Examining the use of computer simulations to promote learning of electrochemistry among college students

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UMI®
Examining the use of computer simulations to promote learning of electrochemistry among college students

by

Han-Chin Liu

A dissertation submitted to the graduate faculty
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

Major: Education (Curriculum and Instructional Technology)

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2005

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This is to certify that the doctoral dissertation of

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For the Major Program
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CHAPTER 1. GENERAL INTRODUCTION

Background

Scientific knowledge is cumulative. Students build science knowledge based on what they already know and on what scientists have discovered from the real world. Scientists use symbols, drawings, and graphics to construct models that represent their ideas and findings from their observations of natural phenomena. Johnstone (1982) argued that there are three levels of representation in chemistry (macroscopic, microscopic, and symbolic) that are used to represent chemistry phenomena and theories. Understanding chemistry requires an individual to interpret the meaning of chemical reactions that are presented at all three levels. Students without sufficient experience may have difficulties understanding these concepts and science phenomena. Some studies have found significant differences in performance between students who use traditional instructional materials and students who use computer simulations in understanding science (Gorsky & Finegold, 1992; Kozma, Chin, Russell, & Marx, 2000; Weller, 1995; Zietsman & Hewson, 1986). According to Paivio’s (1986) dual coding theory, visuals accompanied with text explanation can help students decode the information that is unfamiliar to them. Today’s computer technology provides graphical representations in the form of animations and simulations that are expected to help students relate their prior experience to scientific models and construct their own mental models of chemistry phenomena and theories.

However, one cannot judge the improvement of student understanding simply from the time students spend on computer simulations (Pankuch, 1998). When computer animations are integrated into learning activities, variables such as the learner’s learning style, background knowledge regarding content knowledge, cognitive stage, and computer
operation skills that could affect students’ learning outcome have to be carefully considered (Huppert, Lomask, & Lazarowitz, 2002).

In a computer-assisted learning environment, an individual’s prior knowledge has been found to have an impact on her/his understanding of scientific concepts (Ausubel, 1968; ChanLin, 2001; Gredler, 1996; Mayer & Sims, 1994; Njoo & de Jong, 1993). Prior knowledge level may also affect how an individual interacts with instructional computer simulations and how an individual comprehends the information distributed by the computer programs (Mayer & Sims, 1994). Different computer simulations are designed in different styles and can be integrated into an individual’s learning environment. Research with a focus on the impact of prior knowledge on students’ understanding of scientific knowledge in a computer-assisted learning environment could be helpful in understanding how implementing computer technology efficiently could help students understand science. In addition, each individual may have her/his preference on the design of computer simulations, the format of representations, and the integration with learning activities while using computer simulations to learn science concepts and principles. Some researchers have found that individual differences in learning strategies might affect how students learn and how students use computer simulations (BouJaoude, 1992; Jones & Berger, 1995; Riding & Grimley, 1999; Shute & Glaser, 1990; Simmons & Lunetta, 1993; Veenman & Elshout, 1995). Whereas using today’s computer technology is popular among science educators in helping students understand science concepts, it is important to investigate the influences of an individual’s learning strategies, metacognitive skills, and prior knowledge on their understanding when using computer simulations to learn science in the classroom.
Among the studies reviewed, the majority were conducted in a short-term manner for research purposes. However, this study was conducted in a real classroom setup in which the computer simulations were available for students as part of their learning activities. With the popularity and benefit of using computer simulations for science classes and my research interest in understanding how instructional use of computer simulations has an impact on individuals with different preferences, I have chosen the area of the implementation of instructional computer simulations for my dissertation work.

**Dissertation Organization**

This dissertation is organized into five chapters. Chapter 1 is the general introduction in which the background and the significance of the research topics are addressed. Chapter 2 is an overview of other studies that have investigated factors that influence the effectiveness the instructional use of computer simulations. Issues found by the studies are identified, and meanwhile, the theories on which this study is based and themes that have emerged from prior studies are described in this chapter.

Chapter 3 and Chapter 4 consist of two papers describing the design and the purposes of my study and demonstrating the findings of the study. Both papers will be submitted for publication. Chapter 3 describes the design and results of my quantitative study. The findings are analyzed and organized based on statistical methodology in order to investigate how the use of computer simulations affected student performance and how individual differences such as prior knowledge and learning strategies interacted with the use of computer simulations on students’ understanding.

Chapter 4 includes results from the qualitative design of my study. Students’ interactions with computer simulations and conversations with peers are identified and
organized according to the research interests. The results are presented in the form of case studies of three groups that were composed of students with different prior knowledge levels. Chapter 5 summarizes the major findings and results of the studies described in the papers and identifies common themes from the studies.

The references for each chapter are included immediately following the text of each respective chapter; supplemental material for this study is included in the appendices at the end of the dissertation.

References


CHAPTER 2. FACTORS INFLUENCING LEARNING FROM COMPUTER SIMULATIONS IN CHEMISTRY

A paper to be submitted to the International Journal of Science Education

Han-Chin Liu

Drawings, graphics, images, and pictures have been used to represent various types of information for communication in human society. In science, visual information has been used to represent ideas and theories in a variety of disciplines. Scientists often use drawings, symbols, graphs, and images as means for presenting and explaining findings and discoveries. The visuals and symbols used by scientists are also demonstrated in textbooks and by teachers in order to describe ideas and discoveries in science classes. However, learners without the knowledge and skills to interpret particular types of visuals presented in the textbooks may find it difficult to understand scientific concepts. Images and graphics have been used to help make explicit the phenomena and reactions that text information seeks to explain. It is also argued that teachers sometimes assume that images and graphics are “self-explanatory” and will be understandable to students; nevertheless, the skills and knowledge required for interpreting the visual representations used in particular disciplines is sometimes far more than those needed for everyday pictures (Lowe, 2000). Sanger and Greenbowe (1997a, 1997b) have suggested that alternative teaching strategies (e.g. computer simulations) may be considered in helping students understand scientific concepts.

With the emerging technologies in recent years, information is distributed by way of different types of media, and commonly is presented with a mixture of different types of media. Therefore, today’s students live in an environment in which information is presented
in a variety of visual formats. Traditional textbooks using plain text and static graphics that seek to draw students' attention are now competing with information that is delivered visually in rich media formats such as audio, video, animation, and simulation, in helping students learn science (Lowe, 2000).

Visual representations have been found to help students construct "mental models" (Johnson-Laird, 1983) to explain scientific concepts and principles that are used to clarify natural phenomena (Gilbert, Boulter, & Elmer, 2000; Gilbert & Priest, 1997). The process of model production and model modification is essential to students' knowledge building because it helps learners clarify misconceptions and build new understandings of concepts and theories. Computers are capable of creating visual information that is expected to promote the modeling process. The dynamic graphic representations of information generated by computers are now popular in assisting teachers and students in modeling processes of learning activities. Among those computer-generated media, dynamic graphics such as computer animations are commonly accepted among instructors and science educators as helping students understand scientific theories and concepts. In recent years, computer simulations have been integrated into learning environments by science educators and researchers to help students build mental models of science concepts and achieve conceptual understanding.

Although the use of computer technology is widely accepted by science educators and instructors, individual differences may have an impact on learning in computer-assisted learning environments (Jones & Berger, 1995; Riding & Grimley, 1999; Ross & Schulz, 1999; Schauble, Glaser, Raghavan, & Reiner, 1991; Shute & Glaser, 1990; Simmons & Lunetta, 1993). In instructional theory, the phrase "prior knowledge" refers to the knowledge that a
person has at the beginning of a given learning episode or experience. Prior knowledge is commonly considered one of the most important individual factors that affect learning behavior and learning results (Ausubel, 1968; ChanLin, 1999; Mayer & Sims, 1994). Gredler (1996) argued that students’ prior knowledge of both content domain and problem-solving skills may have an impact on the use of computer simulations that are designed to help students learn science concepts and principles. While computer simulations are popularly accepted by instructors and science educators, how different individuals with different prior knowledge levels respond to computer simulations is worth investigating in order to benefit future students’ learning.

In addition to prior knowledge, an individual’s learning strategy is also one of the variables that may affect a student’s learning outcome with the use of computer simulations. Each individual uses her/his own approach to solve problems encountered in learning activities. Learning strategies, ranging from skills for improved memory to better studying or test-taking skills, refer to methods that students use to learn. Individuals have their own strategies for solving problems during classroom activities and for assignments. When integrating computer technology into a learning environment, it is important to realize how different individuals employ computer technology to learn and how their use of computer technology affects their understanding of science concepts. Research on the influences of an individual’s learning strategies, metacognitive skills, and aptitude on their understanding are discussed in order to realize how computer simulations can be used by different individuals as an effective instructional tool in today’s classrooms.

In this review, investigations of student’s difficulties in learning chemistry concepts are discussed. Meanwhile, research on the effect of using different formats of representation
of information in the learning environment and studies discussing the effect of models and modeling, especially in computer assisted learning environments is reviewed in order to highlight the relationship between the modeling process and the instructional use of computer technology. Next, a description of animations and simulations and their impact on students’ understanding when learning science concepts and theories is documented in this review. Studies regarding students’ learning strategies and prior knowledge in a computer-simulated learning environment are also examined.

**Students’ Difficulties in Learning Chemistry Concepts**

The descriptions provided by the textbook and by the instructor during lectures are the main resources that are used by the students to learn chemistry in traditional classrooms. Students are found to have difficulties understanding chemistry concepts in the context that is set up based on traditional teaching strategies (de Jong & van Joolingen, 1998; Garnett & Treagust, 1992a, 1992b; Hesse & Anderson, 1992; Sanger & Greenbowe, 1997a, 1997b, 2000; Solsona, Izquierdo, & de Jong, 2003).

Sanger and Greenbowe (1997a) investigated students’ misconceptions and understanding of electrochemistry following a course of instruction and provide implications for classroom and science curriculum development. Thirty-four senior high school students were interviewed with questions about electric circuits and oxidation-reduction equations. Conceptual and propositional knowledge statements were used as interview protocol that was administered to identify the knowledge that was required for students to understand electric circuits and oxidation-reduction equations. Some students were found to be confused by the nature of electric current in metallic conductors and in electrolytes, while many students were found to have difficulties identifying oxidation-reduction equations. Misconceptions
regarding definitions of oxidation and reduction were also identified in students' interview answers. Understanding students' misconceptions was necessary to help students learn electrochemistry concepts. In addition, the authors argued that using multiple models to explain scientific behavior was often confusing to students. The authors suggested establishing connections between physics and chemistry concepts, and further, adopting the electron flow model of metallic conductors would help students better understand electrochemistry.

In Hesse and Anderson's (1992) study, three oxidation-reduction reactions were shown to high school chemistry students who had completed a unit on chemical change. Students representing a range of achievement levels were asked to write explanations for the reactions. Eleven students were interviewed and asked to explain their written answers to the questions. Case studies of three students representing three different achievement groups were established and the development framework was extended to the rest of the eight students. This study tried to address chemical knowledge that high school students used to describe chemical change, the function of conservation reasoning in explaining chemical change, and the nature of explanatory ideals used by the students. The results showed that learning about chemical change requires complex changes in the conceptual ecologies of most students. According to the findings of this study, chemical knowledge, conservation reasoning, and explanatory ideals are the three common areas in which students experienced difficulties. In chemistry, conservation reasoning means reasoning with the maintenance of a certain quantities unchanged during chemical reactions or physical transformations in mind. For example, students need to understand that the total number of molecules of a cup of alcohol is not changed when half of the alcohol is vaporized into the air. In terms of chemical
reactions, explanatory ideals are the ability to represent macroscopic chemical reactions using equations and formulas. The authors suggested that both teachers and researchers need to have a deeper understanding of students' misconceptions that influence students' reasoning about chemical change. In addition, researchers argued that traditional teaching methods were thought to be ineffective in helping students learn this topic.

Sanger and Greenbowe (1997b) interviewed 16 introductory college students after electrochemistry instruction using modified questions that originated from research conducted by Garnett and Treagust (1992a). Students answered questions regarding galvanic and electrolytic cells. Students' misconceptions were identified from their answers to the interview questions. Confirming Garnett and Treagust's (1992a) study, the most commonly encountered student misconceptions were notions regarding electron flow through the solution and salt bridge to complete the circuit, the assignment of plus and minus signs to the electrodes, and ignorance of the reaction of water in the cell. New misconceptions such as notions that half-cell potential is absolute and electrochemical cell potentials are independent of ion concentrations were identified in Sanger and Greenbowe's (1997b) study. Although students held misconceptions, they were still able to correctly answer questions regarding the calculation of cell potentials. The findings of this study agree with results from earlier studies (Sanger & Greenbowe, 1997a) that students' ability to solve quantitative exam questions does not guarantee their conceptual understanding of chemical concepts. Sanger and Greenbowe (1997b) argued that the origin of these misconceptions might be from the students' lack of awareness of the relative nature of electrochemical potentials or misleading and incorrect statements from the textbooks. As a result, Sanger and Greenbowe suggested revision of textbooks and integration of conceptual change strategy in instruction (Posner, Strike,
Hewson, & Gertzog, 1982) in order to prevent and reverse student misconceptions. Furthermore, using computer simulations/animations showing the molecular level movement of ions in solution was also suggested by the researchers to assist students in visualizing the change of charge in both electrodes and help them understand the concepts of electrochemistry.

In a follow-up investigation to Sanger and Greenbowe's (1997b) study, Sanger and Greenbowe (2000) investigated the use of computer animations and instruction based on conceptual change theory (Posner et al., 1982) to confront students' misconceptions of electrochemistry. According to the misconceptions found in their earlier study (Sanger & Greenbowe, 1997a, 1997b), Sanger and Greenbowe (2000) sought to determine whether the use of computer animations or conceptual change strategies used in instruction would reduce student misconceptions. College students who enrolled in a single section of an introductory college chemistry course intended for engineering majors participated in this study. Participants were randomly assigned to four groups. Students in the control group received instruction using static chalkboard drawings. Students in the three treatment groups received instruction with computer animations, with conceptual change strategy, and with both treatments of computer animations and conceptual change strategy, respectively. Computer animations depicting the electrochemical process occurring in a copper-zinc galvanic cell were demonstrated three times to students in the treatment groups. Three theories regarding the electron flow in the cell solution were presented to students who were treated with conceptual change strategies. Two of these three theories were based on the misconceptions found in Sanger and Greenbowe's (1997a, 1997b) earlier studies. The average of two prior midterm chemistry examination scores was used as the students' pretest score; immediate and
delayed post-test scores were compared among treatment groups. No treatment effect was found among these four groups. The authors argued that college students did not need visual aids in their learning because they were able to visualize the movement of electrons mentally. Meanwhile, college students could simply be prompted to think about chemical processes at the molecular level in order to apply their chemistry knowledge to answer items in the examinations. The authors concluded that it was likely that the conceptual change strategy contributed more to students’ understanding than did the use of computer simulations.

Four categories of problems students faced when a discovery learning strategy was implemented are described in de Jong and van Joolingen's (1998) review paper. The first category is hypothesis generation. Many students have difficulties understanding the nature of a hypothesis and are not able to use their data to revise their hypotheses. Therefore, students tend to hold on to their original thoughts. As a result, students seem to avoid generating hypotheses because the data is likely to reject their hypotheses. The second category of problems is experimental design. Among the studies de Jong and van Joolingen (1998) reviewed, many showed that students are biased in designing an experiment to agree with a hypothesis rather than to challenge the hypothesis. Some studies showed that students tend to use too many variables in one experiment. Moreover, students were found to design their experiments to generate a desirable outcome rather than to test their model. The third category is data interpretation. Misinterpreting the results in confirming hypotheses is the most common mistake. Students were also found to have difficulties processing information presented in graphs. The fourth category of problems is regulation of the discovery process. Students were found to use insufficient prior domain knowledge to set their goals and to use causal strategy and intuitive decisions to achieve their goals.
The review paper by de Jong and van Joolingen (1998) also illustrated that different methods of support have been found to have a positive influence on students' discovery learning. These methods include providing simultaneous access to information about the domain by using computer simulations and providing learning with assignments, questions, exercises, or games. Regarding the methods of using computer simulations in learning mentioned in de Jong and van Joolingen's (1998) paper, gradually introducing the components rather than fully introducing the structure of the computer simulation at once seems to have a positive impact on student learning using computer simulations.

Solsona et al. (2003) argued that students should learn to interpret the concept of chemical change in both the macroscopic and microscopic domains. Their study focused on a student's conceptual development of chemical change. Fifty-one senior high school students' cognitive development was described in terms of conceptual profiles. Researchers sought to identify students' conceptual profiles regarding chemical change and to characterize the development of their profiles during consecutive years of secondary school. Students' essays were analyzed and their understanding of chemical change was categorized into change of substance, physical properties, structure levels, or no change. Students' conversations were subcategorized as mass conversation, element conversation, and no conversation. Students' explanation of chemical change was distinguished as macroscopic, microscopic, and no relationship subcategories. Students' essays were also categorized as strong, weak, and no global coherence in the text according to their reference to representations of chemical change. At the end of the authors' analysis, an overall category "concept of chemical change" was developed. Students' "concept of chemical change" was categorized into explained, uncertain, or not explained according to the accuracy of interrelation between macroscopic
and microscopic levels in their explanations. According to the content of students’ essays, the results showed that students’ conceptual profiles of chemical change could be identified, and the authors categorized the profiles into interactive, meccano, kitchen, and incoherent categories. Students’ essays in the interactive category showed a coherent and balanced relationship between the macroscopic and microscopic levels of explanation in their essays. Essays in the meccano category were built up fundamentally around microscopic explanation of change without paying attention to phenomena. The discourses of essays which belong to the kitchen profile were built mainly around phenomena. Essays belonging to the incoherent profile did not provide explanation of chemical change. In their findings, 92% of students were not able to understand the concept of chemical change by relating the macroscopic meaning to the microscopic meaning of this concept. When essays were written at the end of school year, they were compared to the essays written at the beginning of school year. The authors concluded that increasing the number of lessons about chemical change and other chemical concepts did not ensure the improvement of students’ understanding of this concept.

According to Solsona et al. (2003), it is useful and meaningful for students whose concept profiles were categorized in the kitchen profile to remember experiments and the behavior of substances used in the laboratory in order to understand chemical change. Students whose conceptual profiles were categorized in the meccano profile tended to memorize atoms, electrons, and bonding in order to understand chemical change. The authors argued that most of the students’ profiles could be seen as incomplete or partially correct instead of incorrect. In addition, many students did not remember the experiments done in the classroom. And finally, the examples of chemical phenomena used in the classroom in Spain
might need further evaluation in order to help students develop an interactive profile of the concept of chemical change.

From the studies reviewed, students were found to have difficulties in understanding a variety of chemistry concepts and theories. Alternative strategies were suggested to help students build understanding and knowledge of chemical phenomena and events that theories seek to explain. Although it is accepted that computer simulations can have a positive impact on students’ understanding, research has suggested that the teaching strategies used with simulations have a dominant impact on student understanding (Sanger & Greenbowe, 2000). Educators and instructors try to help students build the skills that scientists use to construct models that represent natural events and phenomena. However, students with insufficient prior knowledge seem to have difficulties following the path by which scientists reach their goals (de Jong & van Joolingen, 1998). When learning chemistry concepts and principles, an individual seems to have his/her own strategies to handle different learning tasks (Solsona et al., 2003). Therefore, simply increasing lecture time did not seem to increase levels of understanding. Curriculum revision may be necessary to improve students’ understanding. The use of computer simulations and animations has been suggested as one of the alternative teaching strategies to help students visualize the molecular level of chemical reactions (de Jong & van Joolingen, 1998; Sanger & Greenbowe, 1997b). Nevertheless, research has found that teaching strategies seem to have a stronger impact than do the computer simulations on student understanding (Clark, 1994; Sanger & Greenbowe, 2000). Although student difficulties have been identified by a variety of studies, variables that affect an individual’s understanding and solutions that can be used to improve an individual’s learning outcomes still need to be identified by further investigations.
Representations of Information

Information represented in formats such as text, graphs, symbols, and images is commonly used by scientists to explain their ideas and predictions. Information presented in visual formats has been found to add weight to information processing during an individual’s cognitive activities. Paivio’s (1986) dual coding theory hypothesizes that information encoded in both visual and verbal formats is better remembered than that which is encoded in only one of these two formats. Dual coding theory deals with how visual information is processed and stored in memory. It gives equal weight to verbal and non-verbal processing. The theory supposes that there are two cognitive subsystems: one focuses on the illustration and processing of nonverbal objects, and the other deals specifically with language. If information is stored in both verbal and non-verbal forms then it is more easily remembered than information that is coded in either of the formats alone. Information is processed within or between imagery and verbal systems in different ways: representational, referential, and associative (Paivio, 1991). Representational processing activates a particular type of memory by the corresponding type of stimulus. For example, the word “dog” activates information coded in a verbal system whereas a picture of a dog activates information coded in a visual system. Referential processing cross-activates the two types of coding systems, which means the word “dog” can activate the information that is visually coded and the picture of a dog can activate the verbal description of a dog. However, Rieber (1994) argued that the interaction between the visual and verbal information are not always one-to-one because an image may potentially evoke different verbal retrievals at the same time. For example, a picture of a cat not only activates the verbal description of a cat but also may activate the name of the cat if the viewer happens to be the owner of the cat. Associative processing
activates additional information within either system. Dual coding theory has been applied to many cognitive phenomena including mnemonics, problem solving, concept learning, and language.

There has been a great amount of evidence over the years that supports the effectiveness of the use of instructional visual materials on learning (Mayer & Sims, 1994). For example, among the 23 studies Levie and Lentz (1982) reviewed comparing learning with text assisted by visual materials to learning with text alone, only one study showed that learning with text alone was superior. Visual information is now commonly used to accompany the verbal format of information in order to help students understand scientific models that scientists use to explain natural processes, phenomena, and theories. In chemistry, different formats of visuals such as text, symbols, drawings, and graphs are used to represent chemical reactions. However, many students with limited knowledge and experience may have difficulty translating such representations into conceptual understanding (Gorsky & Finegold, 1992). Based on dual coding theory, chemistry educators and researchers have sought to help students build a conceptual understanding of chemical representations using different instructional strategies (Ben-Zvi, Eylon & Silberstein, 1986; Gabel, 1998; Keig & Rubba, 1993; Kozma & Russell, 1997). However, some of the phenomena that theories try to explain require mental visualization of the chemical reactions at the molecular level. Johnstone (1982) argued that there are three levels of representation in chemistry (macroscopic, microscopic, and symbolic) that are used to represent chemistry phenomena and theories. Understanding chemistry requires an individual to interpret the meaning of chemical reactions presented at all three of these levels.
In Kozma and Russell’s (1997) study, chemistry experts were found to be more capable of creating patterns based on symbolic forms such as graphs, animations, and equations to describe phenomena. In their study, first semester undergraduate students were compared to professional chemists and doctoral students majoring in chemistry. Comparisons were made on their ability to meaningfully group representations and on their ability to transfer representations from one to another. Results showed that although novices created more groups of representations, chemistry experts were able to create larger and more meaningful collections of multiple representational forms than were novices. In conclusion, chemists were more capable of converting representations into other meaningful forms of representations than novices. Kozma and Russell (1997) also concluded that students seemed to see only surface features such as numbers, lines, letters, and graphics when analyzing the representations. The authors suggested that students should be encouraged to work in groups and use a symbol system and symbolic learning environment to discuss, debate, and explain their understanding of chemistry. Their findings also implied that well-designed computer applications could also make different types of representations explicit and meaningful to students and help them transform visual materials into meaningful chemistry representations like experts did.

Noh and Scharmann (1997) investigated the impact of demonstrating pictorial presentations at the molecular level on students’ understanding when students were learning chemistry concepts and solving chemistry problems. High school students were treated either with visual materials or with an expository teaching method by the same teacher while being introduced to new concepts, formulas, and chemical equations. Students’ performance was assessed using a Chemistry Conception Test and a Chemistry Problem-Solving Test. Results
showed that students who were treated with visual materials constructed more scientifically correct concepts than students who were treated with traditional instruction. However, no significant differences were found in students' problem-solving ability in both groups. Students in this study simply received lecture with or without the accompanying visual materials. The lack of student interactions and student-controlled learning activities might have contributed to the findings. Researchers suggested that teachers should consider alternative teaching strategies such as collaborative learning and student-centered learning activities to improve interactions between students and to provide control to students for their learning.

ChanLin (1996) investigated the effect of the use of graphic representations integrated with metaphorical strategies for learning biotechnology on students’ understanding of biology concepts. One hundred and twenty college students with a low level prior knowledge of biology were involved in the study. A $3 \times 2$ study was designed with six groups of students who received treatments based on non-graphics, static graphics, and animated graphics, and either with metaphors or without metaphors. Metaphors were used in this study to try to improve the effects of the graphic representations and to emphasize the meaning of graphics in order to help students understand the concepts of biotechnology. A criterion-referenced test was used to assess students’ understanding, and students’ attitudinal responses were gathered using the Instructional Materials Motivational Survey (IMMS). Students who received animation treatments with metaphors scored higher in both the criterion-referenced test and motivational response than students in the other groups. No significant difference was found among the non-metaphor graphic representation treatment groups (non-graphics, static graphics, and animated graphics). The researchers questioned whether students without
metaphors could accurately interpret the graphic objects or animations on the screen. The results supported the hypothesis that using metaphors along with a scenario provided by animation could help facilitate students’ learning. The author concluded that metaphors could be used to make the visual representations more concrete to the learners.

Visual representations in formats such as static and dynamic pictorial images have been found to effectively help students understand scientific phenomena (ChanLin, 1996; Kelly, 1997; Kozma & Russell, 1997; Noh & Scharmann, 1997). Visuals generated by computer applications were suggested to make theories explicit and help students interpret the scientific models like experts do (Kozma & Russell, 1997). Kozma and Russell (1997) argued that visual media also work as tools to promote communication between students and help them achieve understanding. It seemed that the impact of the use of computer simulations on students’ understanding increases when accompanied with alternative teaching strategies. As indicated by ChanLin (1996), the use of graphic representations with metaphors seemed to benefit students more than the use of graphic representations alone.

Although studies have found that computer simulations could enhance students’ learning outcome, the computer simulation needs to be integrated in a learning environment in which well designed learning activities are implanted. In terms of improving students’ understanding, a well-designed learning/teaching strategy seems to be the fundamental element that helps students learn science concepts through the use of computer simulations. The influence of instructional strategies in a computer-assisted learning environment is discussed in the following section.
Active Learning Strategy

In many traditional high school and university classrooms, the most common activity pattern is the instructor talks and students listen. However, research has found that students need to be more actively involved rather than just listen and practice (Chickering & Gamson, 1987). Higher-order thinking tasks are supposed to be the core learning activities in classrooms. To be actively involved, students need to engage in tasks such as analysis, synthesis, and evaluation. Under such an instructional setup, active learning is defined as any strategy "that involves students in doing things and thinking about the things they are doing" (Bonwell & Eison, 1991, p. 2). Active learning is one of the instructional strategies that encourage students to engage cognitively in activities such as hypothesizing, problem solving, discussion, explanation, debate, and brainstorming (Phelps & Damon, 1989). In an active learning environment, the learner constructs her/his own understanding and most of time works collaboratively with other students. Strategies such as group discussions, problem solving, case studies, and role playing were commonly employed to actively engage students in the learning activities. In contrast to a teacher-centered learning environment, an active learning classroom setup provides a student-centered context in which students learn from active investigation and reflection. The use of an active learning strategy has been found to promote students’ problem-solving skills and critical thinking skills; transfer of new information and motivation were also found to be improved by the use of active learning strategies (Goffin & Tull, 1985; Hanks & Wright, 2002).

Recent research has investigated the impact of integrating different formats of computer technology such as on-line home assignments, computer generated graphics, and computer simulations in an active learning environment (Farnsworth, 2001; Skinner &
According to Robinson (2000), an analysis of active learning of scientific concepts is based on models of discovery practiced by scientists. The model includes six components: defining problems, stating hypotheses, designing experiments, collecting and analyzing data, applying results, and making predictions based on the results. Robinson (2000) summarized the problems that students may encounter while using an active learning strategy accompanied by computer simulations. He argued that a review paper would provide guidance not only for designing computer simulations but also about student ability in scientific reasoning. A variety of research found that computer simulations and animations helped students learn scientific concepts in particular disciplines (Kelly, 1997; Khoo & Koh, 1998; Kozma, 1991, 1994; Williamson & Abraham, 1995). However, Clark (1983, 1994) argued that it is likely the strategy of instruction affects student performance rather than the type of media used to deliver instruction. Working collaboratively on problems also has been found to be a valuable teaching strategy because the interaction between students tends to generate conceptual conflicts and promote conceptual change (Basili & Sanford, 1991; Lonning, 1993). In addition, the dynamic graphics generated by computer simulations have been found to promote interaction between group members when students work in groups; therefore, computer simulations can work as a vehicle to encourage communications between group members (Krajcik, Simmons, & Lunetta, 1988; Otero, Johnson, & Goldberg, 1999). Computer simulations allow students to rerun the program and come to agreement after reflecting on their ideas in group discussions. Communication requires students to reflect on and make explicit their conceptions; therefore, such interactions can contribute to the change of students' misconceptions. When used as a part of an active learning strategy, computer simulations can be effective, especially if the programs provide opportunities for learners to
discover the science concepts at their own pace (Horowitz & Christie, 2000; White & Frederiksen, 1998).

Based on an active learning strategy, learning activity with the use of computer simulations seem to help students learn the ways that scientists use to construct models that represent how the world operates. Studies that investigated how students develop their understanding of scientific concepts with the help of computer simulations and animations and how computer simulations affect the modeling process are discussed in the following section.

Models and Modeling with Computer Simulations

As defined by Gilbert and Priest (1997), a model is “a representation of an idea, object, event, process, or system” (p. 751). A model in science is a simplified or replicated representation of phenomena. When notions and entities are used to compose the model, such as energy, it can be seen as an idea. Abstract concepts, concrete unities, and their relationships can be implemented in a model to represent a system. The model can be of an event; and in addition, one or more events within a system can form a model to represent a process if time is integrated as one of the factors (Gilbert et al., 2000). A scientific model can be seen as a collection of ideas that can be run mentally to describe natural phenomena or processes (Giere, 1988; Kitcher, 1984). Commonly, scientific models are used by scientists to explain the data collected and to predict the results of further experiments. In addition, scientific models are evaluated to see if they fit with other models or theories that are accepted in scientific society (Cartier, 2000).

Different modes of representations have been used to represent a model. Media in different formats such as visual, verbal, concrete, mathematical, symbolic, and a mix of these
different types of media have been used to represent models that are accepted in the scientific community (Boulter & Buckley, 2000). According to Boulter and Buckley (2000), in a mathematical model, a variety of symbolic (numbers) and graphical information typically are used to explain scientific rules and theories. For example, arrows and lines are often used to represent the direction and magnitude of force. In addition, the relationship among force, mass, and acceleration is usually represented in mathematical symbols and formulas, such as \( F = m \times a \) when explaining Newton's second law of motion. Chemical equations share the structure and elements in mathematical models to demonstrate the phenomena of chemical reactions. For example, the equation: \( \text{HCl} + \text{NaOH} \rightarrow \text{NaCl} + \text{H}_2\text{O} \) represents an acid-base equilibrium reaction. The “+” symbol in this equation represents the mix or encounter of hydrochloric acid and sodium hydroxide, which is more abstract than the meaning of summing as it is represented in a mathematical model. Meanwhile, the symbol \( \text{NaCl} \), composed of the two symbols “Na” and “Cl,” has the meaning of chemical bonding between sodium and chloride, which is also more complicated than the meaning of the multiplication of two symbols in a mathematical model (Malvern, 2000).

Scientist use symbols and drawings to construct models to describe and explain ideas and discovery. Students need to construct their mental model based on the model represented by symbols and drawings. Johnson-Laird (1993) defined a mental model as the analogies that are made up of an individual's perceptions and experiences of the real world. In his statement, “It is now plausible to suppose that mental models play a central and unifying role in representing objects, states of affairs, sequences of events, the way the world is, and the social and psychological actions of daily life” (p. 397), mental models are related to the structure of cognition. Holland (1986) argued that reasoning processes are based on mental
models: “Models are best understood as assemblages of synchronic and diachronic rules organized into default hierarchies and clustered into categories. The rules comprising the model act in according with the principle of limited parallelism, both competing and supporting one another” (p. 343). In summary, a mental model represents an individual’s view of the real world. How phenomena make sense, how things work, and how to solve an encountered problem are presented in the format of models in an individual’s mind. In terms of learning, helping a learner construct or reconstruct her/his mental models of particular science ideas and theories could be a successful pathway to the understanding of science concepts.

Building a mental model requires an individual to build a cognitive structure with prior experience of her/his real world and how the world works. Students without sufficient experience or prior knowledge will have difficulty mentally constructing the models that are used by scientists to describe natural events and phenomena. Novices have been found to have difficulties relating these models to their mental models (Sanger & Greenbowe, 1997a). Driver and Easley (1978) argued that it is common for students to hold a set of concepts which they use to make sense of the world around them. When learning science, a learner often uses her/his prior experience to mentally build models that represent natural phenomena and events. A mental model that is built based on such experience will possibly represent an individual’s understanding of science concepts that is not scientifically correct. In the early 1980s, a theory of conceptual change was developed by a group of science education researchers (Posner et al., 1982). This theory is based on Piaget's (1964) notions of disequilibration and accommodation and Thomas Kuhn's description of scientific revolution (Kuhn, 1962). Kuhn outlined scientific revolutions as: When a dominant way of observing,
reasoning, evaluating, and accomplishing failed to solve significant problems discovered by
the scientific community, an alternative paradigm had to be available to solve these problems.
These two conditions construct a track toward the adoption of a new structure of thinking.
The process is also called "paradigm shift." Based on the conceptual change principle,
science educators seek to help students understand science concepts by reconstructing
learners' mental models that are used to interpret the world around them. The model
reconstruction process, modeling, therefore could be related to conceptual change processes.

Different types of media and teaching strategies have been used to help students build
mental models that are scientifically correct. Renk, Branch, and Chang (1993) argued that
visual information, which may be presented using various types of media, has an impact on
the development of the viewer's mental model. Mental models are representations in an
individual's mind of real world or imaginary situations. Individuals' mental models could be
built based on the interpretation of the visual information, which is communicated via
pictorial contents, symbols, and other formats of imagery (Ballstaedt, Mandl, & Molitor,
1989; Saunders, 1994). Seel and Strittmatter (1989) argued that a mental model developed
through information processing has an interaction with an individual's knowledge base. The
information being processed might conflict with an individual's existing mental model.
Visual representations provide clues that students can relate to their prior knowledge and
therefore work as a solution to solve encountered problems. Therefore, mental models are
developed consciously and the images help individuals initiate the development of mental
models and solidify the models. The process of model development can be seen as a form of
modeling. In Seel and Strittmatter's (1989) argument, mental model development involves
analogy-making when visual media delivers information and activates an individual's
thoughts. A variety of instructional materials from traditional textbooks to the latest educational technologies contain a number of pictorial representations. Verbal explanations in today's textbooks are commonly accompanied by images and static graphics to help students understand the content and to make a connection between information from the lecture and information from laboratory activities. Pictorial presentation is the most common medium used by science instructors to provide an explanation and analogy of abstract theories or phenomena that students have difficulties understanding. However, some natural phenomena that cannot be observed with the naked eye may require the learners to dynamically visualize their mechanism. Today's computers, with increasingly greater computational power, have played an important role in delivering information presented as dynamic visual media. Computer technology is therefore considered to be effective in delivering visual information and helping an individual construct mental models (Renk et al., 1993). For example, on a computer screen, the trajectory of a moving object can be presented in dots that are left behind the object. The molecular level of chemical reactions can be seen by creating dynamic "enlarged" molecules and atoms on the computer screen (Peters & Daiker, 1982). The magnified molecular level of chemical reactions helps students visualize how the dynamic systems operate during chemical reactions. The impact of dynamic visuals generated by the computer simulations is discussed in the following section.

**Impact of Animations and Simulations**

A computer animation demonstrates a series of visual images that are consecutively displayed on a computer screen. For instructional purposes, computer animations are designed to provide visualizations of processes or events and to communicate abstract concepts and theories to students (Burke, Greenbowe, & Windschitl, 1998). When using
computer animation, commonly the user passively receives the visual information demonstrated on the screen of a computer. However, with the ability to demonstrate molecular level chemical reactions, computer animations have been found to be effective in helping students learn chemistry concepts (Rieber, 1989; Sanger, Brecheisen, & Hynek, 2001; Sanger & Greenbowe, 1997a, 2000). The molecular level of chemical reactions become explicit when the processes are presented in a series of computer generated dynamic images. This feature makes computer animations a powerful tool for an instructor to model students’ learning of the molecular level of chemical reactions (Sanger, 2001).

Computer simulations accept input from users and demonstrate events or outputs using a series of animations according to the calculation of the computer programs. In simulations, reality is represented in a highly modified fashion in order to increase the ability of an individual to understand (Dale, 1969). According to McGuire (1976), use of a simulation is “placing the individual in a realistic setting where he is confronted by a problematic situation that requires his active participation in initiating and carrying through sequences of inquiries, decisions, and actions” (pp. 89-90). The incomplete information gained from simulations forces students to make decisions based on the results in order to solve further problems. With the computational ability of the computer, computer simulations allow the users to manipulate variables in the models that are viewed on the computer screen. As defined by de Jong and van Joolingen (1998), “A computer simulation is a program that contains a model of a system (natural or artificial; e.g. equipment) or a process” (p. 180). As a result, computer simulations are considered to be tools that are valuable for allowing effects of changes to be seen in models before invoking the change in the real world (Marks, 1982). Computer simulations are capable of dynamically generating visual representations that
students can relate to events in the real world. Therefore, one purpose of using instructional computer simulations is to provide opportunities for learners to discover properties of a model or patterns through the collection and analysis of data or information provided by the computer programs. In addition, computer simulations can increase students' enthusiasm and motivation by giving them the chance to explore the simulated environment and conduct simulated experiments at their own pace. The above characteristics tend to promote students' problem-solving skills and have been shown to be effective in causing conceptual change (Gorsky & Finegold, 1992; Weller, 1995; Zietsman & Hewson, 1986).

Gorsky and Finegold (1992) used computer simulations to create dissonance between students' misconceptions and the simulated phenomena. Nine students from 9th to 12th grade in a rural high school were treated with computer animations to help them learn concepts of force. Seven out of nine students had not studied physics. Students completed a pretest in which they answered questions regarding their conceptions of force and motion. Their pretest results indicated they held incorrect conceptions about forces. After they answered the questions, they viewed simulations that conflicted with their alternative conceptions of force and motion. For example, when students chose the answer "Friction is not a force," an animation of a book continued to move along the table horizontally and did not come to rest. When students perceived the conflict between their prior conceptions and what they observed in the simulations, they could access a help system. The help system showed information that was designed to support students to reconstruct their understanding of force. The effects of the simulations were assessed through interviews and class observations. The qualitative results showed that students established correct conceptions about contact force and motion after viewing the unit. In this study, simulations were used to elicit students' non-science
concepts of force and to provide a framework for the acquisition of new concepts. Therefore, the researchers suggested that simulations needed to be used prior to formal classroom instruction and there should be more teacher involvement in helping students to construct new concepts.

Weller (1995) conducted a similar study to investigate a microcomputer system for diagnosing and remedying students' alternative conceptions of force and motion. Eighth grade students, who had studied force and motion two or six months earlier, viewed computer simulations regarding force and motion and were compared to students who completed the test questions without experiencing the simulations. The students were ranked by their teachers according to their achievement in science class in order to determine whether any correlation existed between students' degree of science achievement and possession of their preceding alternative conceptions. Questions on a computer screen regarding force and motion were given to students to diagnose their alternative conceptions. Posttests were also given to students via computer simulations. Students' responses to the questions posed by the computer were automatically saved to be analyzed. In addition, a delayed posttest was given one and half months later to seven students to test the duration that students held the scientific conceptions. In general, students in both groups scored higher on the posttest than on the pretest. Students held fewer alternative conceptions and more scientifically correct conceptions after the instruction than they did before the instruction. Students viewing computer simulations answered more of the posttest questions correctly than did the students in the control group. The immediate posttest results indicated that the computer simulations significantly helped students alter their alternative conceptions in the short term. Five of the seven students who were given delayed posttests scored the same as they did on the
immediate posttest, which showed the robustness of the conceptual change. No significant correlation was found between students' pretest score and teachers' ranking of students' science achievement, which indicated that strong learners also held alternative conceptions. Weller (1995) suggested that science teachers could not assume strong learners need not to be examined for alternative conceptions. Due to the positive results of the study, Weller (1995) suggested that a greater beneficial effect could be obtained if the diagnosis and remediation system were integrated into students' normal classroom context and allowed each student more control and choice to adjust it to match their own progress.

Zietsman and Hewson (1986) investigated the effects of instruction using both microcomputer and conceptual change strategies. Tenth grade students and college freshman without prior knowledge of motion in physics used microcomputer simulations to learn the principles of motion. This group was compared to those who used the relative motion of real objects. The authors examined how remedial sequences of a computer program affected students who were identified as holding alternative conceptions of velocity. To access their conceptions of velocity, students completed an apparatus diagnostic test accompanied by an unstructured interview and a simulated experiment on a microcomputer. The computer simulation was used as the posttest in all cases. The remedial sequences of the computer program were used as the treatment for the experimental group. Students' responses (correct and incorrect) to the simulation were collected by the computer and analyzed qualitatively to see if the same conceptions identified by the real-world experiment also were identified by the simulations. Students' conceptions identified by the simulated tasks showed no difference to the conceptions of velocity identified using real objects. Zietsman and Hewson (1986) concluded that microcomputer simulations provided the same effect on building students'
mental model of motion as the real world experiments. Students viewing remedial sequences of the simulation were more likely to make correct responses. This result indicated that the remedial sequences of the microcomputer program, which used a conceptual change strategy, helped students change their conceptions of velocity.

Simulations and animations can provide richer visual and audio experiences that can be used more effectively by students to learn science. Mayer and Sims (1994) tested the impact of integrating verbal format information, auditory narration, with multimedia learning. Students who heard a concurrent or successive explanation while viewing animations generated more creative solutions in solving their problems. Mayer and Sims (1994) suggested that accompanying verbal information presented in auditory format is more effective in helping the learner to understand content knowledge. Mayer and Sims' findings agreed with Paivio's (1986) dual coding theory that information presented in both visual and verbal formats enhances students' understanding. Although Mayer and Sims' (1994) studies had found that the integration of verbal and visual information improves students' problem-solving capabilities, the researchers also concluded that the success depends on the experience level of the learner. They explained that "when a useful visual model is not presented along with a verbally presented explanation, high-knowledge students are more able than are low-knowledge students to retrieve a source model from long-term memory and to use it to help interpret the incoming verbal explanation," (Mayer & Sims, 1994, p. 391). Therefore, an individual's prior knowledge level seems to have an impact on the effect of the instructional use of computer simulations.
Prior Knowledge and the Use of Computer Simulations

Experience is a common resource from which an individual can retrieve information to connect newly encountered information and acquire knowledge (van Someren & Tabbers, 1998). It has been found that individuals learn better if they encounter information that is related to their experience (de Jong & van Joolingen, 1998; Mayer, 1987). Information that is presented in a variety of manners, such as tables, graphs, images, and animations, has been used to help students organize results and link experiences to the phenomena that theories and concepts seek to explain. Therefore, the skills and prior experience of processing information that is presented in different types of formats could influence how an individual interprets newly encountered information.

In instructional theory, the phrase "prior knowledge" refers to the knowledge that a person has at the beginning of a given learning episode or experience. Prior knowledge is commonly considered to be one of the most important variables that affects learning behavior and learning results (Ausubel, 1968; ChanLin, 1999; Mayer & Sims, 1994; Schauble et al., 1991; van Someren & Tabbers, 1998; Windschitl & Andre, 1998). Gredler (1996) argued that students' prior knowledge in both content domain and in problem-solving skills might affect their use of computer simulations that are designed to help students understand scientific knowledge. Students need to employ their subject domain knowledge to manipulate the variables for their research using particular simulations. Gredler (1996) also suggested identifying the variables that are used in the simulations because the more variables needed for the tasks, the higher the difficulty level of the tasks. Meanwhile, instruction on how to manipulate the variables in the simulations prior to the use of simulations may be helpful to increase positive impact of the use of simulations on students' understanding. Prior
knowledge has been found to help students make more correct predictions and reasonable explanations while they were using computer simulation programs (Schauble et al., 1991). Although van Someren and Tabbers (1998) argued that there was not enough theoretical analysis supporting the correlation between students’ prior knowledge and their learning outcome, findings in Schauble et al.’s (1991) study indicated it is likely that students’ prior knowledge on either problem solving skills or domain knowledge guides students to enhanced discovery strategies.

Njoo and de Jong (1993) investigated the relationship between high school students’ prior knowledge and their understanding of physics concepts in a computer simulation-assisted learning environment. Results indicated that students who had high prior knowledge test scores also achieved high test scores after completing a simulation-based computer lab. Students with a high level of prior knowledge were found to encounter fewer difficulties than students with a low level of prior knowledge. However, no relationship between prior knowledge and the learning patterns of students was found. ChanLin (2001) compared the influence of eighth grade (labeled “novice”) and ninth grade (labeled “experienced”) students’ prior knowledge on their performance on a criterion referenced test regarding physics concepts in learning environments with the assistance of different formats (text, graphic, and animation). Overall, the effect of treatment was significant among novice learners but was not significant among experienced students. However, novice students did not seem to benefit from the use of animation in learning. The researcher concluded that novices might not have enough prior knowledge/experience to process information represented in verbal and animated graphics simultaneously. Therefore ChanLin (2001)
suggested that careful consideration of the use of presentation formats was essential for novice learners.

An individual’s prior knowledge has been found to have a connection with her/his understanding when using computer simulations to learn scientific concepts. In addition, a learner’s prior knowledge level might have an impact on how she/he interacts with instructional computer simulations and how she/he interprets the information delivered by the computer in a computer-assisted learning environment (Mayer & Sims, 1994). Therefore, investigations of the influence of prior knowledge on students’ learning outcome may be helpful to understand how individuals use different approaches to accomplish learning tasks when there are different designs of computer simulations integrated into the learners’ learning environment.

Computer simulations provide an environment that allows learners to solve, discuss, and reflect on the problems embedded in the simulations. In solving those problems, students are encouraged to discuss with their group members when working in groups. Therefore, computer simulations can work as tools to promote collaborative learning, problem solving, and increase in motivation. Although interaction between group members was found to be one of the essential components in helping students learn in a computer assisted environment, only a few studies have investigated, with the use of computer simulations, how different students use different approaches to solve problems and how the individual differences have an impact on an individual’s understanding. Therefore, the effect of individual differences on learning outcomes in a computer simulation integrated active learning environment is worth further investigation.
Learning Strategy

Learning strategies, ranging from skills for improving memory to better studying or test-taking strategies, refer to methods that students use to learn. Individuals have their own strategies for solving problems during classroom activities and for assignments outside the classroom. When integrating computer simulations with an active learning teaching strategy, which demand high involvement in the task and rich interactions with peers, it is important to realize how students respond to the computer simulations, how they interact with group members, and how they approach solving problems. BouJaoude (1992) investigated the relationship between high school students’ learning strategies and changes in their understanding of chemistry. Questionnaires were designed to measure the strategies students used to solve chemistry problems. Results showed that students who scored at or above the mean score on the learning strategies questionnaire (labeled meaningful learners), performed better on a conceptual understanding test than those who scored below the mean (labeled as non-meaningful learners). Therefore, individuals’ learning strategies (cognitive/metacognitive strategies) seemed to influence how students attempted to solve problems. Veenman and Elshout's (1995) investigation indicated that although a number of studies had found that there are correlations between an individual’s aptitude and metacognitive skills (deep orientation, systematic orderliness, evaluation, and elaboration), metacognitive skills mainly contributed to learning in simulation-based discovery environments. Students with low aptitude and a low level of metacognitive strategies were found to benefit from learning in a structured simulation-assisted learning environment. For low aptitude students with a high level of metacognitive strategies, the instructional guidance in a highly structural learning
environment seemed to interfere with their problem solving style and hindered their learning outcome (Veenman & Elshout, 1995).

In psychology, the word “cognition” is used to refer to the mental processes of an individual and can be understood in terms of information processing or processes that involve knowledge, expertise, or learning. “Metacognition” is used to refer to the state or processes of “knowing about knowing,” which can be interpreted as the knowledge and awareness of an individual’s own cognitive processes, how they function, when it’s likely to falter, etc. Students are required to design and perform experiments to explore a domain by generating and testing their hypotheses in a simulation environment; therefore, there are cognitive and metacognitive demands for learning with simulations that involve complex problem solving, reasoning, and discovery learning (van Joolingen & de Jong, 1991; Veenman & Elshout, 1995). However, differences in individuals’ problem solving strategies may have an impact on learning in simulation assisted learning environments (Jones & Berger, 1995; Riding & Grimley, 1999; Ross & Schulz, 1999; Schauble et al., 1991; Shute & Glaser, 1990; Simmons & Lunetta, 1993). In an active inquiry learning environment, discovery progression or shift between hypothesis and experiment is likely vary as a result of individual differences such as the preferences, tendencies, and strategies that individuals exhibit while learning.

The effect of individual differences on learning strategies has been observed by Riding and Grimley (1999). Their study showed that learners who are not able to comprehend ideas as a complete whole did not learn as well as those who can view ideas or concepts in a holistic style from a multimedia presentation of information. Riding and Grimley (1999) argued that students with a limited ability to holistically interpret ideas or concepts in a simulation aided learning environment had difficulty comprehending different modes of
information provided by the multimedia content. Jones and Berger (1995) investigated students’ use of media components of a computer-based chemistry instructional program. Pictures, texts, videos, animations, and experimental simulations were components of the program integrated with questions and concept maps. These components sought to help students create an overall understanding of the content. College students in an introductory chemistry course were involved in the study and their log files of program use were investigated. A variety of usage patterns were found for different students working on the same assignment. Students were found to make use of different components of the program to accomplish their assignment. In addition, the questions and concept maps were used by students to organize the learning content as they worked through the computer application. The researchers suggested further investigations on the design features, such as the navigation features, to understand what type of students benefit from the features most and how these features affect students’ learning and understanding. Additional research on student reactions to the computer program was suggested to understand how different types of instructional media affect an individual’s understanding.

Kozma, Chin, Russell, and Marx (2000) conducted a study to investigate the impact of various graphic features in a computer simulation that helps students learn chemistry concepts. Overall, students using the computer simulations were found to have a significant increase in their conceptual understanding of chemical equilibrium. However, no differences in students’ performance were found between groups using different graphic features. Kozma et al. (2000) argued that students needed to employ different types of cognitive strategies to use the computer simulation efficiently.
Wu, Krajcik, and Soloway (2001) studied how students use on-line information to understand chemistry concepts. Discussion between group members when they were using a computer simulation was found to help students understand chemical representations. In addition, a few individual differences, such as level of engagement and how an individual interacts with group members, were identified as affecting students' learning with the use of computer simulations. However, investigation of additional individual characteristics, such as the strategies they used in solving problems, was not conducted to understand the impact of individual differences on learning with the use of computer simulations.

Ross and Schulz (1999) looked at the impact of students' cognitive learning styles on their learning outcome and on the human-computer interactions using a computer application designed to help students understand the processes and principles of cardiopulmonary resuscitation (CPR). Undergraduate students' learning styles were identified and categorized as concrete sequential (CS), concrete random (CR), abstract sequential (AS), and abstract random (AR). Participants used a computer program to learn CPR. Meanwhile, the sequences and frequency, as well as the time students used the tools and videos, were recorded by the computer program. A pretest and a posttest were given to students to measure their achievement after using computer applications in learning CPR. Although significant differences of students' learning outcomes were found among students with different learning styles, no correlation was found between human-computer interactions and students' learning styles. However, in this study, abstract random (AR) students were found to demonstrate poor interactions with the computer program while abstract sequential (AS) students were found to be highly interested in using the computer program. Concluding from their findings suggest that an extension of time for students who are allowed to use computers, modifications of the
content of the course, and redesign of the computer programs facilitated examination of the interactions between students’ learning styles and the aforementioned factors in a computer-assisted learning environment.

Each individual has her/his preference for the design of computer simulation, the format of representations, and the integration with learning activities when using computer simulations to learn science concepts and principles. With the increasing computational capability of computers and the popularity of electronic media used by science educators and instructors to teach science, an investigation of the influences of an individual’s learning strategies, metacognitive skills, and aptitude on their understanding is necessary for developing computer simulations that can be used as an effective instructional tool in today’s classrooms.

**Summary**

Science theories and principles are the accumulation of wisdom in human society. Discoveries and ideas from the observations of scientists are encoded using text, symbols, drawings, and graphics to represent models that are used to describe these scientific findings. To understand the theories and concepts, one must be able to build mental models using the information provided by models that are accepted by the scientific community. Computer technology is capable of generating dynamic visual information that has been found to help those who have insufficient skills to interpret the meaning of models that are represented in static visual format. While some research has demonstrated that computer simulations have a positive impact on student understanding of scientific concepts and natural phenomena, variables such as individual differences, the design of the learning activities, and the teaching strategy on which the learning environment is based, have been discovered to have an impact
on students' learning outcome with regard to the efficiency of the instructional use of computer simulations. To understand how the instructional use of computer simulations can benefit students in understanding science theories and principles, further investigations of variables such as individual differences, design of learning activities, and teaching strategies may be helpful to improve students' learning outcome of scientific knowledge.

References


CHAPTER 3. THE IMPACT OF INDIVIDUAL’S MOTIVATED LEARNING STRATEGIES AND PRIOR KNOWLEDGE IN A COMPUTER SIMULATED ENVIRONMENT FOR LEARNING ELECTROCHEMISTRY CONCEPTS

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Introduction

Many chemistry concepts are difficult to understand, especially for first year college students and high school students (Garnett & Treagust, 1992a, 1992b; Sanger & Greenbowe, 1997a, 1997b; Solsona, Izquierdo, & de Jong, 2003). In a traditional classroom, the teacher lectures while students take notes on specific scientific topics. Students work individually on assignments and tasks; furthermore, the teacher rarely integrates assignments that encourage discussion and collaboration among students. As a result, many students learn to calculate correct answers for test questions without fully understanding the chemistry principles and theories (Nakhleh, Lowrey, & Mitchell, 1996; Nurrenbern & Pickering, 1987; Pickering, 1990; Sanger & Greenbowe, 1997a; Sawrey, 1990). Traditional lecturing is not effective in helping the majority of students understand abstract chemistry concepts, even when teachers use a portion of their lecture time to explain chemistry concepts (Hesse & Anderson, 1992; Noh & Scharmann, 1997). In addition, the static graphics and text in chemistry textbooks do not seem to effectively help students comprehend concepts and visualize chemical reactions. Sanger and Greenbowe (1997a) argued that alternative teaching strategies, such as instructional use of computer animations that are designed to be used in an inquiry approach can help students understand chemistry concepts. In addition, active learning is one of the instructional strategies that encourages students to engage cognitively in activities such as
hypothesizing, problem-solving, discussion, explanation, debate, and brainstorming (Phelps & Damon, 1989). The use of an active learning strategy has been found to promote students' problem-solving skills (Goffin & Tull, 1985; Hanks & Wright, 2002).

**Representation of Information**

A variety of media and instructional technologies have been used to help students conceptually understand chemical representations (Ben-Zvi, Eylon, & Silberstein, 1986; Gabel, 1998; Keig & Rubba, 1993; Kozma & Russell, 1997). Text, symbols, and static graphics are used to represent chemical reactions. In addition, formulas and equations are commonly used to represent and to communicate explanations for reactions and chemical phenomena. "Dual coding" theory (Paivio, 1986) hypothesizes that information encoded in both visual and verbal formats is better remembered than information encoded in only one of these two formats. Pictorial and graphic formats of information are commonly used in classrooms to help students understand concepts and theories that explain chemical phenomena.

However, some of the phenomena that theories try to explain require mental visualization of the chemical reactions at the molecular level. Johnstone (1982) argued that understanding chemistry requires an individual to use three levels of representation: microscopic, macroscopic, and symbolic. For example, static drawings presented in textbooks or drawn by the instructor on the blackboard only partially represent chemical reactions at the molecular level. Today's computer technology is affordable and able to generate high quality images and dynamic graphics. As a result, computer animations can be designed to display visually, using images that convey 3D representations, dynamic events such as chemical reactions.
Recent research has investigated the impact of integrating different formats of computer technology, such as on-line homework assignments, computer generated graphics, and computer simulations, with active learning strategies (Farnsworth, 2001; Skinner & Hoback, 2003). When used as a part of an active learning strategy, computer simulations can be effective, especially if the program provides opportunities for users to discover the targeted concepts (Horowitz & Christie, 2000; White & Frederiksen, 1998). A variety of research has found that computer simulations and animations can help students learn scientific concepts in various disciplines (Kelly, 1997; Khoo & Koh, 1998; Kozma, 1991, 1994; Williamson & Abraham, 1995). However, Clark (1983, 1994) argued that it is likely the strategy of instruction affects student performance rather than the type of media used to deliver instruction.

**Computer Animations and Simulations**

A computer animation demonstrates a series of visual images that are consecutively displayed on a computer screen. For instructional purposes, computer animations are designed to provide visualizations of processes or events and to communicate abstract concepts and theories to students (Burke, Greenbowe, & Windschitl, 1998). When using a computer animation, the users passively receive the visual information that is demonstrated by the computer animation. The dynamic content, represented in a rich visual format, make explicit abstract concepts and natural phenomena that are not otherwise easily visualized. In a computer simulation modeled learning environment, the computer generated output, which can be a series of animations, results of calculations, and responses in different media formats, depends on the input from the user of the simulations (Thomas & Hooper, 1991; van Joolingen & de Jong, 1991). According to McGuire (1976), simulation is "placing the
individual in a realistic setting where he is confronted by a problematic situation which requires his active participation in initiating and carrying through sequences of inquiries, decisions, and actions” (pp. 89-90). As defined by Gilbert and Priest (1997), a model is “a representation of an idea, object, event, process or system” (p. 751). Scientists use symbols, drawing, and graphics to build models with which they can explain natural events or phenomena. With the computational ability of the computer, computer simulations allow the users to manipulate variables in the models that are viewed on the computer. As defined by de Jong and van Joolingen (1998), “A computer simulation is a program that contains a model of a system (natural or artificial; e.g. equipment) or a process” (p. 180). As a result, computer simulations are considered to be tools that are valuable for allowing effects of changes to be seen in models before invoking the change in the real world (Marks, 1982). Computer simulations are capable of generating visual representations dynamically which students can relate to the models in the real world. Therefore, one purpose of instructional computer simulations is to provide opportunities for learners to discover properties of a model or patterns through collecting and analyzing data or information provided by the computer programs.

Active Learning Strategy

One approach to implementing an active learning strategy is to encourage students to work collaboratively on problem solving. Working collaboratively on problems has been found to be a valuable teaching strategy because the interactions among students tend to generate conceptual conflicts and promote conceptual change (Basili & Sanford, 1991; Lonning, 1993). Collaborative learning encourages students to work in teams on problems and projects, accompanied by strategies that promote discussion, explanation, and debate
among students. Computer simulations can be integrated with collaborative learning techniques to help students learn chemistry. It has been found that computer simulations can be used as a vehicle to promote communications and collaborations among group members (Krajcik, Simmons, & Lunetta, 1988; Otero, Johnson, & Goldberg, 1999). Communication requires students to reflect on and make explicit their conceptions. Computer simulations allow students to rerun the program and come to an agreement after reflecting on their ideas during group discussions. As a result, simulation-mediated conversations and interactions between students can facilitate conceptual development. Discussion among group members while using a computer simulation was found to help students understand representations of chemical reactions (Wu, Krajcik, & Soloway, 2001). In addition, students using the computer simulations were found to have a significant increase in conceptual understanding of chemical concepts (Kozma, Chin, Russell, & Marx, 2000).

Kozma et al. (2000) found that collaboration among students around the use of computer simulations improved their inquiry activities through the social construction of knowledge. They concluded that technologies and models needed to be used within a social context. Although computer simulations have been found to have an impact on students’ understanding of science concepts, Kozma et al. (2000) argued that students need to be encouraged to use a greater variety of cognitive strategies that promote deep understanding of the information obtained through the simulation in order to use simulations effectively. An active learning environment allows students to participate in class beyond the role of passive listeners and note takers. Students are given more control on their learning in an active learning environment than in a traditional classroom. However, each individual may use different approaches to solve the problems encountered in learning activities. Students may
have different levels of cognitive skills and use different learning strategies to solve problems. Therefore, it is valuable to understand individual differences related to students’ learning strategies and profile of cognitive skills in learning activities with the use of computer simulations.

**Individual Differences**

In a simulation-integrated learning environment, students are required to design and perform experiments to explore a domain by generating and testing their hypotheses. There are cognitive and metacognitive demands for learning that involve complex problem solving, reasoning, and discovery learning (van Joolingen & de Jong, 1991; Veenman & Elshout, 1995). Therefore, individual differences in learning strategies may have an impact on learning in simulation-assisted learning environments (Jones & Berger, 1995; Riding & Grimley, 1999; Ross & Schulz, 1999; Schauble, Glaser, Raghavan, & Reiner, 1991; Shute & Glaser, 1990; Simmons & Lunetta, 1993). In an active inquiry learning environment, discovery progression or shift between hypothesis and experiment is likely to be varied as a result of individual differences such as the preferences, tendencies, and strategies that individuals exhibit when learning.

Learning strategies refer to methods that students use to learn. For example, some students use mnemonic procedures to improve memory, some study by trying to relate new information to existing knowledge, while others simply try to memorize meanings of major terms. Individuals have their own strategies for solving problems presented in classroom activities and assignments. When integrating computer simulations with an active learning teaching strategy, it is important to understand how students’ learning strategies affect their understanding of science concepts. In BouJaoude's (1992) study, students who scored at or
above the mean score on the learning strategies questionnaire (labeled “meaningful learners”) performed better on a conceptual understanding test than those who were below the mean (labeled “non-meaningful learners”). Veenman's and Elshout's (1995) investigation indicated that although a number of studies had found that there are correlations between an individual’s aptitude and metacognitive skills (deep orientation, systematic orderliness, evaluation, and elaboration), metacognitive skills mainly contributed to learning in simulation based discovery environments. When there were multimedia presentations of information involved in learning activities, Riding and Grimley (1999) found that learners who were not able to comprehend ideas as a complete whole did not learn as well as those who could view ideas or concepts in a holistic style. Riding and Grimley (1999) argued that students with a limited ability of holistically interpreting ideas or concepts in a simulation aided learning environment had difficulty comprehending different modes of information provided by multimedia content.

These three studies demonstrate that individual differences seem to have an impact that may influence how students make use of computer simulations. Thus, a more in-depth investigation of the influences of individuals’ learning strategies, metacognitive skills, and aptitude on their use of simulations is needed in order to develop the understanding that is necessary for effectively using computer simulations as an instructional tool.

The phrase “prior knowledge” refers to the knowledge that a person has at the beginning of a given learning episode or experience. Prior knowledge is commonly considered one of the most important variables that affects learning behavior and learning results (Ausubel, 1968; ChanLin, 1999; Mayer & Sims, 1994). Gredler (1996) argued that students’ prior knowledge of both content domain and problem-solving skills might have an
impact on the use of computer simulations that were designed to help students understand chemistry knowledge. Njoo and de Jong (1993) investigated the relationship between high school students’ prior knowledge and their understanding of physics concepts in a computer simulation assisted learning environment. Results indicate that students who had high prior knowledge test scores also achieved high scores on an assessment test taken after completing a simulation-based computer lab. Levels of difficulty with the tasks to be accomplished seem to be related to the levels of prior knowledge of the individual. Some research results show a contrary influence of prior knowledge. ChanLin (2001) compared the influence of learning environment with different formats of materials (text, graphic, and animation) and also examined students’ prior knowledge on a criterion reference test of physics concepts. From the findings, ChanLin concluded that novices might not have enough prior knowledge/experience to process information represented in verbal form and animated graphics simultaneously. Careful consideration in the use of presentation formats was suggested for novices.

In a study investigating the role of constructivist instruction and college students’ epistemological belief when using computer simulations to enhance conceptual change, students’ epistemological belief was found to interact with the modes of instruction (Windschitl & Andre, 1998). College students with more advanced epistemological belief performed better after using a cardiovascular simulation with less structured instruction, while students with less advanced epistemological belief performed better after using a cardiovascular simulation with more structured instruction. Windschitl and Andre (1998) concluded that students with more advanced epistemological belief seemed to fit better in a
less didactic simulation assisted learning environment. However, further investigation of students’ emotional reaction toward the instruction was suggested to confirm this hypothesis.

Individuals’ prior knowledge has been found to have a connection with their learning. However, the mode of instruction and the format of representations seem to have an impact on the effect of prior knowledge on learning. Additional investigation of how prior knowledge interacts with the instructional design of computer simulation learning environment is warranted.

Examining Computer Simulations for Teaching Electrochemistry

The present study was designed to investigate college students’ learning of electrochemistry in a learning environment that included the use of computer simulations. Based on the findings reported above, the role of individual differences in prior knowledge and in learning strategies was also examined. Among a series of computer simulations developed for learning chemistry, four computer simulations were used in this study. These computer simulations were designed by a chemical education research group directed by a professor in the chemistry department. The Macromedia Flash MX™ program was used to produce and modify the computer simulations. Macromedia Flash MX™ can be used to create animations and simulations that can be accessed either over the Internet or as stand-alone programs on operating systems such as Windows or Mac OS. The computer simulations are available on the following web site:

Simulation 1: Activity Series of Metals

The "Activity Series of Metals" simulation was designed to demonstrate oxidation-reduction reactions between different metals and solutions containing different metal ions (Figure 1). An activity series is a list of substances ranked in order of relative reactivity. The activity series is a useful guide for predicting the products of metal displacement reactions. For example, placing a strip of zinc metal in a copper (II) sulfate solution will produce metallic copper and zinc sulfate, since zinc is above copper in the series. A strip of copper placed into a zinc sulfate solution will not produce an appreciable reaction, because copper is below zinc in the series and can't displace zinc ions from the solution.

As illustrated in Figure 1, users can choose from any of the four metals, magnesium (Mg), copper (Cu), zinc (Zn), and silver (Ag), by clicking on the button in front of the chemical symbol. Four metal strips made of the same metal appear when any of the four metals is selected. By clicking the "Click here to put the metals into the solution" button, the metal strips merge into the solutions. Each solution contains one kind of metal ions. Colored shapes appear on the strips indicating ions from the solution have reduced on the strips when the metal of the strip is more active than the metal that is in ion form in the solution. The color of the shape is designed to match the color of the product of real reactions. Users are able to rank the reactivity of the four metals by comparing the number of reactions that took place in the solutions.
**Simulation 2: Voltaic Cell**

When users click on the "Activity 2" button (Figure 1), the scene of the simulation is switched to the "Voltaic Cell" simulation. The Activity Series of Metal simulation was combined with the Voltaic Cell simulation because these two topics are related and are studied during the same laboratory period. The Voltaic Cell activity simulates the settings of a real voltaic cell (Figure 2). Voltaic (galvanic) cells consist of two separate compartments, called "half cells," containing electrolyte solutions and electrodes that can be connected in a circuit to a voltmeter placed between the two electrodes within the circuit. Oxidation takes place on the electrode called the "anode" where the atoms that the electrode is composed of lose electrons, which are then passed through conducting wires in a circuit. Reduction happens on the electrode called the "cathode" where ions in the solution receive the electrons passed through the circuit by the anode. In order for oxidation and reduction reactions to occur, the circuit must be completed by connecting the two separated half cell compartments. The connection between the two compartments is done by using some conducting medium.
that allows ions to pass from one half cell to the other. The conduction medium is called the
"salt bridge." The principles of the salt bridge are not addressed in this simulation in order to allow
users to focus on the relationship of oxidation-reduction within voltaic cells.

There are two sets of buttons on both the right and left sides of the screen. Each set of
buttons is composed of two buttons labeled either "Metal" or "Solution." A list of buttons and
symbols for the metals copper (Cu), zinc (Zn), and silver (Ag) appear when users click on the
"Metal" button. A list of buttons and formulas indicating the solute in each solution, such as
copper sulfate (CuSO₄), zinc sulfate (ZnSO₄), and silver nitrate (AgNO₃), appear when users
click on the "Solution" button. When users click on any of the buttons next to the metal
symbol, a metal bar is shown connected to the terminal. When users click on any of the
buttons next to the formula of the solutions on the list, the solution selected shows in the
beaker. Users can determine the two electrodes (anode and cathode) of the cell and solutions
in the beakers by selecting the metals and solutions on both sides. By clicking on the power
switch of the voltmeter, animations of the reactions in both beakers take place. The
movement of electrons through the circuit, the movement of ions in the solutions, and the exchange of electrons between ions and atoms in the beakers are illustrated in the animations. Note that only when the metals and solutions are correctly set up will the animation of electron movement take place. For example, if a user selects zinc metal in a copper sulfate solution rather than in a zinc sulfate solution, an animation shows copper ions moving toward the zinc metal bar and depositing on the metal bar while the zinc metal bar dissolves and zinc ions are passed into the solution in the same beaker. This reaction occurs because zinc is more active than copper. In such a situation, no electron movement will be displayed because the exchange of electrons happens only inside one of the beakers.

If the cell is correctly set up, the resulting voltage of the cell is calculated by the program on the basis of the standard reduction potentials of the metals on each electrode; the value of the voltage is shown on the display panel of the voltmeter.

**Simulation 3: Voltaic Cell (Electromotive Force) and Concentration**

The third simulation was developed based on the second simulation (Voltaic Cell) but gives users the additional option of changing the molarities of ions in both solutions (Figure 3). The electromotive force (EMF) is the maximum potential difference between two electrodes of a galvanic or voltaic cell. This quantity is related to the tendency for an element, compound, or ion to acquire or release electrons. The EMF of an oxidation-reduction reaction in a voltaic cell is determined not only by the type of reaction, but also by the concentrations of the reactants and products (i.e., the reducing agent and oxidizing agent). The voltage of the cell varies according to the differences of molarities between the solutions in the half cells.

This simulation shares the same structure and interface as the Voltaic Cell simulation. In order to help users experience the effects of concentration differences of the solutions on
the cell potential, the simulation allows users to select different molarities of metal ions in each solution. Also, a table that lists the standard reduction potentials of different metals appears when the user moves the mouse over the button labeled “E° of Metals” on the lower right side of the screen (Figure 3). The table was designed to provide users the values of the standard reduction potential of the metals so that they could predict the resulting voltage of the cell. In addition, two buttons labeled “Molecular level reaction” appear on the beakers when the animation of electron movement ends. Clicking on any of the buttons pops up a window that illustrates the molecular level of the reaction between the metal atoms on the bar and metal ions in the solution (Figure 3).

Simulation 4: Quantitative Aspect of Electrolysis

Electrolysis is a process by which electrons are forced through either a chemical cell or a power supply, thus causing a chemical reaction. The positive charge usually attracts electrons, and the electrode providing electrons is called a cathode, because reduction takes place on it. The “Electrolysis” simulation borrows the mechanism from the Voltaic Cell series simulations. However, additional control and information were added to the power supply
which functions as a voltmeter in the Voltaic Cell and Voltaic Cell (Electromotive Force) and Concentration simulations.

While the power supply shows the values of the voltage produced in the Voltaic Cell simulation, it displays the voltage applied to the beakers that will drive the electrolysis reaction and the resulting current in the electrolysis simulation. The power supply also has an indicator that displays the amount of time the voltage will be applied to the cells. Users can vary the amount of time for the electrolysis reaction (Figure 4). Since an electrolysis reaction requires voltage to drive the electrons and force the reaction, users are given the opportunity to set the values of the voltage, current, and length of time to be applied. Users choose the values of voltage and time by using the mouse to drag the sliders below each display panel on the power supply that shows the respective values (Figure 4). When users set the current, the value of the voltage is calculated by the computer program and vice versa. However, when the simulation operates, the time selected by the users moves faster than real time does. This feature allows the users to observe the effects in a shorter period of time than the reaction would really take and allows the user to explore the simulation with more situations per unit of real time than the user could do with physical equipment. The choices available for metal bars for the electrolysis reaction on both electrodes are nickel and iron, and the choices for solutions in the bath for reaction are nickel (II) nitrate (Ni(NO$_3$)$_2$) and iron (II) nitrate (Fe(NO$_3$)$_2$). The mass of the metal bar on either electrode can be modified by dragging the slider under the names of the metals in this simulation (Figure 4). The mass of each metal bar changes according to the position of the slider. This feature is designed to help users compare the change of the masses at either electrode at the end of the reaction. All the sliders in this simulation were designed so that the respective values increase as the slider is dragged.
toward the right. As the simulation runs, the boxes as well as the sliders are hidden and the options

![Figure 4. Electrolysis.](image)

of the simulations are disabled to avoid interruption of the algorithm of the program. Two additional boxes colored in blue (Figure 4) are designed to display the changing masses of metals bars on both electrodes; therefore, these two boxes are not hidden while the reaction proceeds.

The minimum voltage for the electrolysis to take place is calculated by the program according to the standard reduction potentials of the metal strip on the anode. A warning window shows when the voltage is set lower than the required voltage for the reaction to take place (Figure 5).
Similar to the other simulations, animations of the microscopic level of the reactions such as the movement of ions in solutions, the metal deposits on the metal bar of the cathode, and the movement of electrons in the circuit are illustrated according to the users’ choices of metals and solutions.

Because the purpose of developing computer simulations is to help students understand chemistry concepts, it is essential to understand how computer simulations affect their learning outcome and how different individuals benefit from using computer simulation. Studying the above-mentioned issues, therefore, can result in the improvement of computer simulation and further, can help more students understand chemistry concepts.

The present study was conducted in order to better understand: (a) how the use of computer simulations affect students’ understanding, and (b) how individual differences such as prior knowledge and learners’ learning strategies have an impact on students’ learning outcomes with the assistance of computer simulation. The research questions for this study were:
1. Under the framework of an active learning strategy, will computer simulations designed to teach electrochemistry positively influence students’ achievement and understanding on assessments of both laboratory practical knowledge and electrochemistry concepts?

2. Under the framework of an active learning strategy, does students’ prior knowledge, as measured by total points earned in their first semester general chemistry course and by total points earned from a chemistry diagnostic test given at the beginning of their first semester general chemistry course, interact with the treatment condition in determining students’ performance and understanding on assessments of both laboratory practical knowledge and electrochemistry concepts?

3. Under the framework of an active learning strategy, does students’ motivational orientation and learning strategy, as measured by questionnaire, influence the performance and understanding, for students in the treatment group, on either the laboratory practical examination or the electrochemistry problems on the final examination?

**Methodology**

**Participants**

The target population for this study was freshmen students, typically 18 and 19 years old, at a university in the Midwestern U.S. Electrochemistry is one of the topics included in a second semester introductory chemistry course in the chemistry department. Because the student’s point totals from the prerequisite course were used as a measure of prior knowledge in the covariance analyses, only students who had completed the prerequisite introductory level chemistry course were included in the present study. Fifty-two students signed up for
the study; however, only 47 students completed the on-line survey and were selected as the treatment group students. Among the total of 188 students who had completed the same introductory general chemistry course in a prior semester, a matched group of 47 students was selected as the control group. To select the control group, the range of treatment group students’ total points from the prior semester introductory course was scaled into ten intervals from high to low. For each of these ten intervals, the same number of students as the number of treatment group students in that interval were randomly selected to be the control group students. Thus, the total number of control group students both overall and within each interval matched the number of students in treatment group. A total of 94 samples were selected, and their test scores were used for this study.

Design

In order to answer the research questions, this study involved a quantitative research design. To answer research questions 1 and 2, a two-group design was implemented. The treatment group of students used computer simulations while they studied chemistry. The control group of students did not use the computer simulations, but spent the same amount of time on the laboratory activities and lecture as the treatment group. In all other respects, the instruction received by the control and treatment groups was the same. A regression analysis, described in the data analysis section, was used to examine the relationships between treatment and student achievement and the interactions among treatments and prior knowledge.

To answer research question 3, all 47 students in the treatment group were asked to answer an on-line survey regarding students’ motivation orientation and learning strategies prior to their electrochemistry laboratory activities. A regression analysis, described in the
data analysis section, was used to investigate the relationships between students’ motivated orientation/learning strategies and their performance.

*Instructional Materials*

*The Nature of the Course*

The course for this study was the second semester course of a two-semester course sequence in introductory chemistry for non-major students. The first semester class was a prerequisite to the second semester class. The two-course sequence explores chemistry with an emphasis on concepts, problems, and calculations, and focuses on principles and quantitative relationships, stoichiometry, chemical equilibrium, acid-base chemistry, thermochemistry, rates and mechanism of reactions, changes of state, solution behavior, atomic structure, periodic relationships, and chemical bonding. Electrochemistry, acid-base equilibria, thermodynamics, nuclear chemistry, and descriptive topics (non-metals, transition metals, coordination compounds, organic compounds, polymers, and biological molecules) are the topics covered in this course.

Lectures were given four times each week in four 1-hour periods. Unannounced quizzes were given in lecture. Questions selected from chapters in the textbook and covered by the lecture were assigned to students each week. Students were required to turn in their assignments during a recitation meeting that was held each week to help students with the assigned questions. During each recitation meeting, teaching assistants helped students on their understanding of the assigned homework questions. Students were able to discuss with the teaching assistants the methods of problem solving and the nature of the presented concepts and principles, and to ask questions. The teaching assistants also took charge of
helping students in the help center, a classroom in which students were able ask questions of teaching assistants.

Three 1-hour examinations were given during the semester to test students' understanding of concepts and principles covered by the lecture. A 2-hour comprehensive final examination was given at the end of the semester. Students' grades were based on the accumulated points from the 1-hour examinations, the final examination, homework assignments, and lecture quizzes. The electrochemistry items on the final comprehensive exam are listed in Appendix A.

The Laboratory

The lecture course was a prerequisite or co-requisite for the laboratory. Only those who either had taken the lecture course or were currently taking the lecture course in the same semester were eligible to take the laboratory. Students needed to attend a 3-hour laboratory period each week. Each week in the laboratory, they conducted experiments that involved the same concepts and principles that were covered by that week's lecture. Teaching assistants facilitated each laboratory section and helped students by briefly explaining the principles and procedures of the experiments, answering questions, and grading students' laboratory reports. Students were also required to find the "Material Safety Data Sheet" (MSDS) of the substance that they would be working with for each laboratory period on the chemistry department's web site and answer a few short questions as the safety assignment for each laboratory. Two laboratory practical examinations were given to students to test their understanding of the principles, concepts, experimental procedures, and techniques of each laboratory experiment. Practical examinations were given at the middle and at the end of the semester. Grading for the laboratory was based on the points gained from laboratory reports
(70%), safety assignments (10%), and practical examinations (20%). The electrochemistry items on the lab practical examination are presented in Appendix B.

Textbook

The textbook used in this course was *Chemistry: The Central Science* (Brown, LeMay, & Bursten, 2000). It consists of 25 chapters covering chemistry concepts and principles that are described in a previous section of this paper. Static illustrations of macroscopic and molecular levels of chemical reactions, natural phenomena, and equipment are used in the book to help students visualize the text that describes chemistry concepts. An “Exercise” section at the end of each chapter serves to help students review their understanding of the content and consists of questions that are categorized according to the principles covered in the chapter. Students’ homework assignment questions were selected from the questions in this section by the instructor.

Laboratory Manual

The laboratory manual was edited by the laboratory supervisor of the chemistry department and is composed of 16 topics covering the same content as the lecture. Basic chemistry concepts and principles are introduced at the beginning of each topic followed by the procedure section for the experiment. A list at the end of each topic functions as the checklist for the teaching assistant to grade student laboratory reports (Appendix C). Eight items of the list are used to check if students have completed all the required sections of their report such as title, purpose, procedure, data/observation, balanced equations, calculations, results, and discussion. Two items work as an evaluation of students’ preparation and understanding of the overall laboratory. Students are required to cut out the list and staple it to their laboratory report before turning in their report.
Tutorials for the Simulations

Three tutorials were developed to assist students manipulate the simulations (Appendix D). The tutorials were handed out to students when they started to use the simulations. In general, these tutorials served as the manual for using the computer programs as well as the questions to determine students’ understanding of the concepts behind the computer programs. The first part of each tutorial contains instructions, such as “Start the software and construct a zinc-copper electrochemical cell using 1.0 M Zn$^{2+}$ and 1.0 M Cu$^{2+}$ solutions,” which guides students to set up the equipment of the simulated experiment. The instructions are followed by questions that collect students’ understanding of the topic covered. For example, questions such as “For the voltage that you are measuring, is this $E_{\text{cell}}^{\circ}$ or $E_{\text{cell}}$? Please explain,” follow the above mentioned instructions and collect students’ background knowledge regarding electrochemistry. Questions in the second part of each tutorial are more open-ended. For example, “Construct an electrochemical cell for which the EMF of the cell is greater than +1.10 V. Before doing the simulation, predict the EMF of the cell,” provides limited information for students and therefore requires them to use their knowledge of electrochemistry to explore the concepts that the simulation seeks to help students understand.

Equipment and Setting

The study was conducted in a chemistry laboratory in which students conduct their laboratory activities. The computer simulations were installed and prepared for student use on two laptop computers with Internet connections. Students needed to complete their normal laboratory activities as well as the computer simulations in a 3-hour period. In order to save participants’ time, a web page that embedded the simulations was open and ready for use.
Instruments

Prior Knowledge

The total points students earned from the prerequisite introductory chemistry lecture course and laboratory in the prior semester were collected as a measure of the students' prior knowledge of basic chemistry concepts and laboratory practical skills. In addition, students' total points gained from a chemistry diagnostic test called the "ACS California Chemistry Diagnostic Test" (ACS diagnostic test) taken in the prior semester also were obtained. The test provided a measure of students' chemistry backgrounds before they enrolled in the prerequisite course. The ACS diagnostic test was developed by the Division of Chemical Education of the American Chemistry Society (ACS) and has been released annually since 1934. The ACS diagnostic test was designed to be used as either an end-of-course test or placement exam for high school level or higher. It was designed to assess students' conceptual understanding and knowledge in the fields of general chemistry, organic chemistry, analytical chemistry, physical chemistry, inorganic chemistry, biochemistry, polymer chemistry, basic mathematic abilities, and high school chemistry. The coefficient alpha of the test is 0.87 based on a sample of 4023 students as reported in Karpp's (1995) study. The high value indicates the test is internally consistent.

The ACS diagnostic test was given to students who enrolled in the prerequisite course at the very beginning of the course to evaluate their general chemical background and mathematic ability. The questions used for this diagnostic test were published in 1997. Forty-four multiple-choice items were used in the diagnostic test. Thirty-three items tested students' chemistry background and the other 11 items tested students' basic mathematic abilities. The ACS diagnostic exams are "closed" exams. Because copying the test items is
forbidden, only the cover page of the test booklet is shown in Appendix E. Also, a table of composite norms and test statistics, reported by the Division of Chemical Education of ACS, is listed in Appendix F.

Motivational Orientation and Learning Strategy

A Motivated Strategies for Learning Questionnaire (MSLQ; Pintrich, Smith, Garcia, & McKeachie, 1991) was used to measure students' typical learning strategies (Appendix G). The MSLQ was developed to assess college students' motivational orientations and their use of different learning strategies in college courses. Two sections comprise the MSLQ, a motivation section and a learning strategies section. Items such as "I'm certain I can understand the most difficult material presented in the readings for this course," assess students' self-efficacy for learning and performance. Items such as "Even if I have trouble learning the material in this class, I try to do the work on my own, without help from anyone," assess students' learning strategy about help seeking. On the items, students rate themselves on a seven point Likert-type scale from not at all true of me (1) to very true of me (7). There are two categories in the questionnaire. One is motivated strategies and the other is learning strategies. The six scales in motivated strategies are "Intrinsic Goal Orientation" (4 items), "Extrinsic Goal Orientation" (4 items), "Task Value" (6 items), "Control of Learning Belief" (4 items), "Self-Efficacy for Learning and Performance" (8 items), and "Test Anxiety" (5 items). The nine scales in learning strategies are "Rehearsal" (4 items), "Elaboration" (6 items), "Organization" (4 items), "Critical Thinking" (5 items), "Metacognitive Self-Regulation" (12 items), "Time and Study Environment" (8 items), "Effort Regulation" (4 items), "Peer Learning" (3 items), and "Help Seeking" (4 items). Note that Pintrich et al. (1991) reported Cronbach's alpha values for the questionnaire scales.
ranging from .52 to .93 indicating moderate reliability of the questionnaire. Some of the items in MSLQ may not be appropriate for testing students' motivation/learning strategies in a particular learning environment.

Students' responses to these scales were used to investigate the relationship between their cognitive/metacognitive strategies and their performance in a computer simulated environment.

**Achievement**

Students' scores on the electrochemistry portion of the laboratory practical exam and the final comprehensive exam were used as measures of their understanding of chemical concepts. The final comprehensive examination contained 9 multiple choice items out of 42 total items, each worth 3 points that assessed students' understanding of electrochemistry concepts (Appendix A). The laboratory practical exam was composed of multiple choice questions, open-ended questions, and diagrams that required students to identify electrodes, half cells, and flow of electrons. Thirteen out of 14 items related to electrochemistry. These items assessed students' knowledge of electrochemistry concepts as well as their laboratory skills (Appendix B). The points assigned to each item varied with a total 35 points available on the scale. A reliability test was performed on the items of these two exams to determine if these two measures could be combined as one measure.

**Procedure**

The instructional unit and assessments took up three laboratory periods in three consecutive weeks, a total of nine hours of laboratory sections. Students were asked to log in to a server on an Internet web page in order to use the computer simulations (Figure 6). Printout tutorials including instructions, tasks, and questions were handed out to the
participants when they started to use these simulations. The activities described above required participants to answer these questions from their observations and the data demonstrated by the computer simulations.

Figure 6. Login in window.

**Week 1: Recruiting Volunteer Participants**

Announcement of this study was made in the laboratory 1 week prior to laboratory sections that covered electrochemistry. Informed consent forms were sent to students in the laboratory and only students who agreed to participate were selected for this study. Next, students who volunteered completed the MSLQ survey on-line.

**Week 2: Oxidation-Reduction Reactions and Electrochemistry**

All the students in the laboratory period tested different combinations of actual voltaic cells. The students placed two different metal strips into their own metal sulfate solutions in wells and used a piece of filter paper rinsed with sodium nitrate (NaNO₃) solution as the salt bridge to connect the two half cells. Students were guided by the teaching assistant and the lab manual to repeat the experiment and measure the resulting voltages obtained when different metals and solutions were used. In each experiment, students used copper metal and
its sulfate solution in one of the half cells, but used different metals and their sulfate solutions in the other half cell. The treatment group students were asked to find a partner from among the participants so that they could work on the simulation together. Partners worked together as a group for each of the laboratory sessions in which the simulations were used. During the lab, each group needed to use part of their laboratory time to access the Activity Series of Metals simulation. Because this laboratory covered topics of oxidation-reduction and voltaic cell, a button labeled “Activity 2” was included in the Activity Series of Metals simulation that would reveal the Voltaic Cell simulation when it was clicked. Students first followed the instructions on the tutorial to test each metal with different solutions and ranked the metals according to their observations. In the second simulation, students were told to connect a zinc-copper cell and answer questions in the tutorial from their observations.

**Week 3: Voltaic Cell EMF**

The actual laboratory in Week 3 focused on the influences of concentrations of each of the half cell solutions on the resulting voltage of the cell. All the students worked in groups of two to prepare solutions of copper sulfate (CuSO₄) and zinc sulfate (ZnSO₄) in concentrations of 1.00M, 0.100M, 0.0100M, and 0.00100M. Next, students placed copper and zinc metals in their sulfate solutions. The half cells were then connected with filter paper rinsed with sodium nitrate (NaNO₃) solution as the salt bridge. The participants measured and recorded the voltages produced by the different molarities of the solutions.

The treatment participants were asked to work, in their groups, on the Voltaic Cell (Electromotive Force) and Concentration simulations. The simulations illustrated the same ideas as the actual laboratory activities, but provided additional options for changing molarities for the solutions on both the anode and the cathode. As in the previous laboratory,
each group was required to turn in their tutorial with answers from their observations of the simulations.

*Week 4: Electrolysis*

This section of laboratory was the last laboratory period for the course. In the actual laboratory activity, students were asked to connect a copper strip, the anode, and a stainless steel strip, the cathode, with a power supply. The strips were placed into a copper sulfate ($\text{CuSO}_4$) solution. For this task, copper ions in the solution would be reduced to the stainless steel strip when the power supply was turned on. Students were instructed to record the time, current, and the voltage applied for the electrolysis reaction and measure the change of the masses on both electrodes.

The treatment participants were required to work in their groups on the Electrolysis simulations. As usual, this simulation illustrated the same ideas as the actual laboratory activities, but provided choices of nickel and iron metals rather than copper and stainless steel as the metal strips on both the anode and the cathode. Accordingly, the choices for the ions in solution were nickel and iron rather than the copper ions used for the laboratory. As mentioned in an earlier section, only when the voltage was set higher than the minimum necessary reaction voltage did the animation start. The differences in the masses before and after the electrolysis process of the metal bars were calculated by the program. Students were instructed to record the results of their observations on the tutorial sheet. Each group was required to turn in their tutorial with answers from their observations.

*Week 5: Laboratory Practical Examination*

All the students took the laboratory practical examination in this week.
Week 7: Final Examination

All the students took the final comprehensive exam in this week.

Data Analysis

A reliability test was implemented on the final comprehensive scores and the laboratory practical scores to determine if these two scores could be combined and be analyzed as one measurement. If the lab practical and final examination scores could be combined, then a single covariate analysis of variance could be used to assess the research questions. A covariate analyses of variance using the students’ total on their final comprehensive and lab practical exams as the dependent variables, their chemistry diagnostic test score and total prerequisite course points as covariates, a dummy code for the treatment/control as fixed variables, and the interaction between treatment and prerequisite course points as the predictors were also used to assess the relationships described in research question 2.

A regression model using only treatment group students’ diagnostic test score, prerequisite course points, and scores from the MSLQ as independent variables, and their final performance as the dependent variable was used to test research question 3 since only the students in the treatment group had completed the MSLQ survey.

Results

A significance test of the treatment group and control group students’ prerequisite course points and their ACS test scores was performed to investigate if there were differences of students’ prior chemistry knowledge between treatment and control group students. No significant differences between the treatment (mean prior course points = 80.82, mean ACS = 70.68) and control (mean prior course points = 80.74, mean ACS = 71.23) groups were found.
on the prerequisite course points \((p < .966)\) or on the ACS test score \((p < .861)\). These results indicate that students in both groups were approximately equivalent in prior chemistry knowledge before the study began.

**Item Reliability Analysis**

Points for each item of the final comprehensive and laboratory practical exams of 188 students were collected in order to perform a reliability analysis on the test items. All statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS, 1999). In the internal consistency analysis, the initial Cronbach's Alpha value was .6334, but reached .7023 when items 22, 23, 24, and 25 were removed from the scale (Appendix H, Tables 1 and 2). Thus, items 22, 23, 24, and 25 were not included in the scale. The total points earned on the remaining relevant items on both the final comprehensive exam and laboratory practical were calculated and used as the dependent variable in the statistical model.

**Treatment Effect**

Table 1 shows the mean scores of both groups. Although the mean score for the treatment group was higher than that for the control group, no significant differences \((p = .064)\) on student’s performance were found between the treatment and control groups, \(F(1,87) = 3.521, p < .064, MS_{\text{error}} = 23.22\).\(^1\) Although the mean score of female students

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\(^1\)Additional covariate analyses of variance on each test item were performed to examine whether the treatment affected students’ understanding on particular concepts. In each analysis, points on each test item were used as dependent variables, treatment and gender were treated as fixed variables, and total prerequisite course points and ACS diagnostic test scores were used as covariates. In addition, interactions between prerequisite course test scores and treatments were also included in the model. Since these were repetitive item-by-item analyses, the appropriate level of Type I error needed to evaluate the entire set of hypothesis test results is \(\alpha = .05/22\) items.
(35.7) was higher than the mean score of male students (33.7), no significant gender differences were found in treatment group, $F(1, 46) = 1.538, p < .221$, $MS_{\text{error}} = 28.55$.

Table 1

Mean Scores, Standard Deviations of Simulation and Non-simulation Groups

<table>
<thead>
<tr>
<th>Condition</th>
<th>Sex</th>
<th>$M$</th>
<th>$SD$</th>
<th>$n$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simulation</td>
<td>Male</td>
<td>33.7</td>
<td>4.04</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>35.7</td>
<td>6.00</td>
<td>29</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>34.9</td>
<td>5.37</td>
<td>47</td>
</tr>
<tr>
<td>Non-simulation</td>
<td>Male</td>
<td>33.0</td>
<td>6.00</td>
<td>29</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>32.3</td>
<td>7.40</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>32.7</td>
<td>6.51</td>
<td>47</td>
</tr>
</tbody>
</table>

Prior Knowledge and Treatment Effect

No significant interactions between the covariates and treatment condition were found in the results. However, students' prerequisite course point total significantly related ($p < .0001$; Appendix H, Table 5) to student performance, $F(1,87) = 3.521, p < .064$, $MS_{\text{error}} = 23.22$.

The high correlation between prerequisite point total and ACS score ($r = .626$) indicated that both the prerequisite point total and ACS score demonstrated students' prior chemistry knowledge. However, no significant relationship between ACS test score and
student performance was found ($p < .168$). The fact that only one of these covariates predicted performance is not surprising because they are highly correlated ($r = .626$).

Motivational Orientation and Learning Strategies

Because there are two categories of items ("Motivation" and "Strategy") in the questionnaire, two internal consistency analyses were used to test if the scaled scores of the items in each category could be combined. The Cronbach's alpha was 0.75 when the Test Anxiety scale was removed from the "Motivation" category. Therefore, the total score across the scales, excluding the Test Anxiety in the Motivation category, was calculated and used as one of the independent variables in the data analysis. Meanwhile, the Cronbach's alpha of the scales in the Strategy category was 0.8804. As a result, the total scores of the scales in the Strategy category were calculated and used as another independent variable in the data analysis. To assess the relationships between MSLQ scores and performance, a covariate analysis of variance was performed using students' performance as the dependent variable and student total scores on the motivational orientation scales except for the Task Anxiety scale, total scores on the learning strategies scales, and score on the Task Anxiety scale of the MSLQ as the predictors. No significant effect was found for student performance on motivational orientation and learning strategies (see Appendix H, Table 6).

In order to determine whether students using computer simulations in learning demonstrated different learning styles that may have had an impact on their learning outcome, correlations between each of the motivational strategy scales and learning outcome were calculated from the treatment group students' learning style scores and compared to the correlations reported in Pintrich et al.'s (1991) study. The results are shown in Table 2.
Table 2 shows that there is no real relationship between the survey and learning outcomes in this situation. There were moderate relationships, at best, in Pintrich et al.'s (1991) normative group. However, in the present student, the motivational strategies assessed by the Pintrich et al.'s questionnaire did not seem to relate to learning outcome to the same extent as they had in the Pintrich et al. (1991) study.

Discussion

This study was designed to examine three research questions: Under the framework of active learning strategy,

1. will computer simulations designed to teach electrochemistry positively affect students’ performance and understanding on assessments of both laboratory practical knowledge and electrochemistry concepts,

2. does students’ prior knowledge interact with the treatment condition in determining students’ performance and understanding on assessments of both laboratory practical knowledge and electrochemistry concepts,

3. does students’ motivational orientation and learning strategy influence the performance and understanding of students in the treatment group on either the laboratory practical examination or the electrochemistry problems on the final examination?
Table 2

*Correlation Between Learning Strategy Scores and Learning Outcome*

<table>
<thead>
<tr>
<th></th>
<th>Treatment group</th>
<th>( p ) (2-tailed)</th>
<th>Pintrich et al.'s (1991) study</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intrinsic Goal Orientation</td>
<td>.14</td>
<td>.359</td>
<td>.25</td>
</tr>
<tr>
<td>Extrinsic Goal Orientation</td>
<td>-.02</td>
<td>.899</td>
<td>.02</td>
</tr>
<tr>
<td>Task Value</td>
<td>.14</td>
<td>.363</td>
<td>.22</td>
</tr>
<tr>
<td>Control of Learning Belief</td>
<td>.24</td>
<td>.100</td>
<td>.13</td>
</tr>
<tr>
<td>Self-Efficacy for Learning and Performance</td>
<td>.13</td>
<td>.367</td>
<td>.41</td>
</tr>
<tr>
<td>Test Anxiety</td>
<td>-.05</td>
<td>.730</td>
<td>-.27</td>
</tr>
<tr>
<td>Rehearsal</td>
<td>-.01</td>
<td>.973</td>
<td>.05</td>
</tr>
<tr>
<td>Elaboration</td>
<td>.08</td>
<td>.597</td>
<td>.22</td>
</tr>
<tr>
<td>Organization</td>
<td>-.07</td>
<td>.625</td>
<td>.17</td>
</tr>
<tr>
<td>Critical Thinking</td>
<td>-.02</td>
<td>.895</td>
<td>.15</td>
</tr>
<tr>
<td>Metacognitive Self-Regulation</td>
<td>.06</td>
<td>.707</td>
<td>.30</td>
</tr>
<tr>
<td>Time and Study Environment</td>
<td>-.03</td>
<td>.859</td>
<td>.28</td>
</tr>
<tr>
<td>Effort Regulation</td>
<td>.07</td>
<td>.643</td>
<td>.32</td>
</tr>
<tr>
<td>Peer Learning</td>
<td>.15</td>
<td>.307</td>
<td>-.06</td>
</tr>
<tr>
<td>Help Seeking</td>
<td>-.08</td>
<td>.586</td>
<td>.02</td>
</tr>
</tbody>
</table>
The Influences of the Computer Simulations on Students' Achievement and Understanding

The first purpose of this research study was to examine the influence of the use of a series of computer simulations on student learning of electrochemistry. As noted above, some previous research had demonstrated that the use of simulations could facilitate the learning of chemistry, but not all studies were positive. In the present cases, students who used the simulations did not do significantly better than matched students who did not. One of the possible reasons is that the limited number of subjects might have weakened the power to detect the differences of students' performance between treatment and control groups. There was only a small sample of students in the treatment and control conditions. With such a sample size, the study may not have had sufficient power to detect a statistical difference. The observed power for detecting the group differences is .458 (Appendix H, Table 5), which means the probability that a statistical significance test will reject the null hypothesis for a specified value of an alternative hypothesis is less than 50%. If too few subjects are used, a hypothesis test will result in such low power that there is little chance to detect a significant effect. The mean for the treatment group is higher than that for control group. The difference between students' performance might be significant if the sample size could be increased. The low power of the data indicates that a larger sample size study is needed for further investigation into understanding the impact of the use of instructional computer simulations.

Among those students who used computer simulations to learn electrochemistry, although the mean score of female students was high than the mean score of male students, no significant gender differences were found. Becker (1989) argued that achievement scores in physics and chemistry vary with regard to gender. Typically, female students do not perform as well as male students (Kahle, 1990a, 1990b). Kahle (2004) argued that the impact
of gender differences on students’ physics and chemistry performance might be viewed as a response to the teaching and learning environment. Although there are no significant differences found in this study, the average achievement score of female students were found to be higher than male students in the treatment group. A further study with sufficient sample size would be helpful to understand if an active learning environment with the use of computer simulations eliminates the impact of gender differences on student performance in physics and chemistry.

In terms of the reliability of the test items, the alpha value for the reliability test only reached an acceptable level of .70 after items 22, 23, 24, and 25 were removed. The nonadditivity test on the test items was significant (Appendix H, Table 2). This result demonstrates a multiplicative term as well as possible interaction among test items in the model for data analysis. The low reliability of the test items might also have contributed to the insignificance of the results. Some of the test items did not seem to be clearly related to the computer simulation content. For example, item 21, “A solution of PtBr₂ is electrolyzed using two platinum electrodes. Assuming no gas evolution at the cathode, for how many seconds must a current of 1.93A to deposit 1.95g of Pt metal?” asked students to calculate the mass of platinum deposited on the cathode after the electrolysis process. This question focused on the calculation of the mass of the electrolysis product. The focus of this question is not perfectly related to the simulation content because the computer simulations focused on the mechanism of the reactions such as the reactivity of the metals and the spontaneity of a reaction. The size of effect of the computer simulations would be smaller due to the remote relationship between the simulation content and the test items.
In addition, two of the items on the overall test were from items in the laboratory practical exam; these items tested students in the area of electron flow in the cell and related specifically to Activity 1 and Activity 2 of the simulation activities (Task 1a and Task 2a, see, Appendix B). However, even on these items, no significant differences were found in students' achievement on these two items (Lab 1A, $p < 0.819$; Lab 2A, $p < 0.541$; Appendix H, Table 4). Despite the fact that the simulations demonstrated electron flow, the treatment group students did not seem to benefit from viewing these submolecular level animations generated by the computer simulations. One study (Sanger & Greenbowe, 1997b) has suggested that college students might be able to generate mental models of simple microscopic levels of reactions by viewing static graphics and pictorial information. It is possible that in this study, students in both groups could predict the direction of electron flow using their mental models built on the drawings and descriptions in the lecture and in the textbook. A more in-depth study examining how students build their understanding of the molecular level reactions from static and dynamic graphics could be important to realize to the reason why the computer simulations did not provide better support than the static graphics.

From the activity logs collected and stored in the database, most of the group pairs spent approximately 13 to 18 minutes using the computer simulations during their 3-hour section of laboratory activity. The simulation activities using computer simulations were designed to be short for students to finish the tasks in short periods of time because the participants also had to complete the rest of the assignments for the laboratory activities. Under these conditions of use, several factors may have reduced any potential benefits of simulations. The students had a very short period of time to use the simulations and were
asked to complete tasks in which they needed to get answers. These are instructional conditions that focus students on the task and don’t lead them to engage in the critical reflection needed to promote deep learning. Because students in the treatment group needed to complete more tasks in the same amount of time as students in the control group, it is likely that the overall cognitive load was greater for students in the treatment group. Sweller and Chandler (1994) has shown that high levels of cognitive load can interfere with reflective learning. It is possible that too much cognitive workload hindered students from interpreting the meaning of the animations and relating the animation to electrochemistry concepts.

Integrating the computer simulations into the laboratories might have reduced the potential value of the simulations because of the limited time to use the using computer simulations.

As a result, it seems that the computer simulation activities also need to be extended to possibly improve their impact on student understanding. From the in-class observation, there did not seem to be sufficient time to allow fruitful interactions between individual group members during the computer simulation activities. The interaction between individual group members is an important component that helps students in understanding science concepts in an active learning environment (Farnsworth, 2001; Skinner & Hoback, 2003). Studies (Krajcik et al., 1988; Otero et al., 1999) have also found that computer simulation could work as vehicles to promote student interaction, initiate conceptual conflicts, and reform student understanding. It is likely that more activities that involved the use of computer simulation might be helpful in helping students understand electrochemistry. Another possible reason for the results is that, although the computer simulation activities were designed based on the idea of promoting an active learning strategy, the setup for students’ real world laboratory activity was not designed for the same approach. Spending less than 20 minutes engaging in
active learning computer simulation activities during a 3-hour period of "cook book" style laboratory may have been insufficient to demonstrate the impact of an active learning strategy. It is possible that students were distracted by accomplishing the assignments for the laboratory and therefore did not have high involvement in the computer simulation activities. As a result, students might have been distracted by the traditional instructional tasks and the purpose of promoting deep learning in an active learning environment was therefore weakened.

The findings suggest a better integration of computer simulations and learning activities than that in the current study is needed in order to improve students' understanding of electrochemistry. As a result, the design of the computer simulations and how they are used instructionally needs to follow the goal of the learning activity and teaching strategy. Therefore, a research design for participants that focuses mainly on the computer simulations without the distraction of extra tasks should be considered for future study.

Despite this instructional intent, the results indicated that the treatment group did not seem to benefit from the use of instructional computer simulations. A second major reason students may not have benefited from the treatment was that they did not attend to one of the important features. One of the computer simulations' features was to generate dynamic visuals that gave students the opportunity to view, at the molecular level, reactions that took place in the electrochemistry cells. Many students in the treatment group did not seem to elect to view these animations. The failure to use the instruction feature probably contributed to the failure of the treatment group to perform better than control group students from watching the computer animations. In terms of drawing students' attention, the simulations may need some features to help students attend to the critical features. The simulations in this study showed
animations of molecular level reactions in the beakers of the electrodes. It would be helpful if a pop-up window showing the animation of molecular reactions had larger scale graphics than the symbols such as “Cu2+” used in the simulations for the current study to better draw students’ attention to the electron exchange between different molecules. Integrating narrations into computer animations has been found to help students relate human-computer interactions to human-to-human conversations (Mayer, Sobko, & Mautone, 2003). It could also be useful to have narration accompany the computer simulations to increase students’ engagement in the computer simulation activities.

As argued by Clark (1983, 1994), technology per se (or any instructional innovation or approach) does not influence learning in and of itself. It is the teaching and learning strategies used with the technology that affects students’ learning and understanding. The implications of these lines of reasoning are that:

1. A more complete investigation of how to utilize the simulations as part of a chemistry learning experience is needed. For example, the simulations could become a homework activity completed singly or in groups outside of class or laboratory or the simulations might replace the real laboratory. Kozma et al. (2000) suggested building a learning environment with the use of computer technology. In the context of a representation-enriched technological environment, students would be provided with the experiences of scientists in a scientific community. Such technological environment gives students the opportunities to investigate, discuss, and build their knowledge.

2. Features could be changed in the simulation that would lead students to attend to critical aspects of the displays. Mayer et al. (2003) found that orally presented
voice-overs could be combined with animations to focus student attention on relevant details. Siegler (1980), working with elementary students, found that programming in activities could lead students to attend to necessary features also that learning was enhanced.

Interaction between Prior Knowledge and Treatment Effect

No interaction between treatment condition and prior knowledge was found from the data analyses. However, a significant effect of prior knowledge as a covariate indicated that students’ prior knowledge affected their learning. Although both students’ prerequisite course points and ACS test scores were used as the covariates to analyze the impact from prior knowledge, only their prerequisite course point total had a significant effect on their learning outcome. The ACS diagnostic test was taken five months before students finished their prerequisite chemistry course. The ACS test tested students’ basic chemistry knowledge as well as mathematic skills, whereas students gained domain-specific knowledge from the prerequisite course. The domain-specific knowledge students gained from the prerequisite course is more consistent with what they learned during the current course. In addition, course performance may reflect motivational factors that are less well captured in standardized tests. In the jargon of statistics, prior course total and ACS were multi-collateral, that is, they reflected and shared overlapping variance. Given the greater regency of the ACS and the fact it probably reflects motivation, therefore, it is not surprising that the prerequisite course point total contributed more to the effect on student performance than did the ACS diagnostic test. To assess this possibility, I reran the analysis with only ACS as a covariate in the regression. Under these conditions, ACS was significantly related to the outcome measure.
Finally, ACS and Prior Course Total were correlated ($r = .63$) as were ACS and outcome measure ($r = .29$) and Prior Course Total and outcome measure ($r = .58$).

Rogers (1969) argued that knowledge gained is significant when discovering new information in a situation that requires an individual to recall prior knowledge. He defined this process of discovering new information as experiential learning. Experiential learning allows individuals to place abstract concepts into context by providing an environment where the prior knowledge must be recalled. Prior knowledge plays an important role in constructing new knowledge from newly confronted information (Bruner, 1960; Piaget, 1964). The purpose of the computer simulations was to work in a context that required students to retrieve their prior knowledge in order to accomplish tasks. Students’ concepts therefore could be revealed, modified, and rebuilt while solving the problems encountered when they were carrying out tasks. The impact of using computer simulations was found to be nonsignificant in this study showing that the students may not have processed the information from the computer simulations well. Therefore, the nonsignificance of the use of computer simulation seems to demonstrate that it was students’ prior knowledge that mainly affected student understanding of electrochemistry. This finding verifies the argument from previous studies that it is important to pay attention to the role of students’ prior knowledge when integrating computer simulations into a learning environment (Ausubel, 1968; Gredler, 1996).

Influence of Students’ Motivational Orientation and Learning Strategy

In the present study, neither the motivation nor the learning strategy scores from the MSLQ significantly predicted performance. Previous studies using the MSLQ have shown relationships between students’ motivation/learning strategies and their learning performance (Barlia & Beeth, 1999; Bong, 1997; Garcia & Pintrich, 1992; Hammann & Stevens, 1998;
Motivation has been found to have a positive correlation with student performance (Barlia & Beeth, 1999; Higgins, 2000; Niemczyk et al., 2001). However, the findings of the current study indicate that the impact of students' motivation and learning strategies on their performance did not seem to be significant when using the series of computer simulations to learn electrochemistry concepts. One of the possible reasons for the results is that the sample size for this study (47 students) may not have been large enough to provide enough power for this study (Appendix H, Table 5). Also, the assessments used in the current study were different from the assessments used in the above-mentioned studies. The difference in the nature of the assessments tools may also have had an effect on the result of student performance and therefore may have influenced the findings of the current study. In addition, the volunteer nature of the sample could have possibly narrowed the range on a few of the variables and thus the size of a possible relationship was limited by the restricted range.

Another possible factor that could have affected the results is that the items tested, students' learning strategies such as rehearsal, organization, time for studying, study environment, and self-regulation, seemed to fit better in traditional classrooms because the MSLQ was designed to assess students' learning strategies in long term learning activities. The items in the MSLQ assessed students' strategies that required their decision-making strategies during their learning activities in long term situations such as organization, rehearsal, time for studying, and study environment. On the other hand, the treatment group students used the computer simulations for a short period of time during their laboratory activities. In addition, due to time constraints, students in the treatment group working on the computer simulation activities had to follow the tutorial to accomplish the designated tasks.
As a result, the MSLQ might not be relevant in assessing the relationship between students' motivational learning strategies and their learning outcome in such a short-term situation in which students didn't have a chance for deep engagement. A redesign of the questionnaire to test students' motivation and learning strategies for the computer-assisted environment could be helpful to realize the impact of computer simulations on different individuals.

In summary, many variables possibly affected the insignificant relationship between students' motivational learning strategies and their learning outcome in a learning environment with the use of computer simulations. In addition, the learning strategies an individual uses in learning activities may not be the same in different learning environments. Further investigations with improvement on the issues discovered in this study are needed to have a better understanding of how different students benefit from the use of instructional computer simulations.

**Conclusions**

Computer simulations have long been used to help students learn science concepts. Various factors may affect students' learning outcomes when they are using computer simulations to learn abstract science concepts. The present research did not find that use of computer simulations integrated into chemistry laboratories facilitated student learning. Although the results show that the computer simulations might not be beneficial to all the students in this study, the research group that developed these simulations has received positive comments from chemistry students, teachers, and instructors because these simulations are available on the Internet. Among these comments received, examples such as, “I found your website of chemistry animations while desperately seeking ways to help eighth graders visualize what's happening at the molecular level,” and “You, yourself, and your
group have did job very useful for the General Chemistry teachers who want to demonstrate
the chemical processes during their lectures for the college students," show computer
simulations used in this study worked as tools in helping instructors and students demonstrate
and visualize molecular levels of chemical processes in real science classrooms. The failure
to find a significant effect may have been due to the brevity of the simulation experience, the
fact that students were not led to attend to critical features of the simulations, and the
differences between the instructional strategies for the laboratory and for the computer
simulation activities. In this study, it is obvious that students' prior chemistry knowledge
seemed to dominate students' learning outcomes in a learning environment accompanied by
the use of computer simulations. Although computer technology has the ability to generate
dynamic visuals in order to help students visualize molecular level of chemical reactions,
computer simulations alone did not seem to help students in learning chemistry concepts.
Computer simulations that are capable of demonstrating visual representations of microscopic
nature phenomena may draw learners' attention easily, but the design of learning activities
seemed to play a crucial role in maximizing the potential of the computer technology and
benefit students in learning.

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and Winston.

in conceptual change learning in science*. Paper presented at the Annual Meeting of
the National Association for Research in Science Teaching, Boston, MA.


CHAPTER 4. HOW COLLEGE STUDENTS USED COMPUTER SIMULATIONS TO LEARN ELECTROCHEMISTRY

A paper prepared for submission to the Journal of Research in Science Teaching

Han-Chin Liu

Introduction

Many chemistry concepts are difficult to understand, especially for first year college students and high school students (Garnett & Treagust, 1992a, 1992b; Sanger & Greenbowe, 1997a, 1997b; Solsona, Izquierdo, & de Jong, 2003). To understand chemical concepts, it is crucial that learners be able to visualize the molecular level of chemical reactions (Johnstone, 1982). Computer technology is capable of generating visual information in either static or dynamic formats. The visual information is commonly used to help learners visualize natural phenomena at the molecular level. The present study investigated how students made use of computer simulations of chemical phenomena that were integrated into a college chemistry course. The study sought to explore how students interacted with computer simulations and how this interaction affected their understanding of electrochemistry concepts.

Teaching Strategies

In a traditional college chemistry classroom, the teacher lectures on particular scientific topics while students take notes. Both in large institutions, where introductory classes are typically large, and in smaller institutions, lecture is the predominant teaching strategy used in most classes. Students usually work individually on assignments and tasks. As a result, many students learn to solve problems on examinations by mechanically calculating answers without fully understanding the relevant chemistry concepts (Pickering, 1990; Sanger & Greenbowe, 1997a). Even though instructors attempt to explain and teach
chemical concepts during classes, traditional lecturing does not seem to effectively help the majority of students understand abstract chemical concepts (Hesse & Anderson, 1992; Noh & Scharmann, 1997). Sanger and Greenbowe (1997a) argued that alternative teaching strategies, such as computer simulations designed to be used in an inquiry approach, can help students understand chemistry concepts.

The use of an active learning strategy has been found to promote students' problem-solving skills (Goffin & Tull, 1985; Hanks & Wright, 2002). Active learning is a collection of instructional strategies that encourages students to engage cognitively in activities such as hypothesizing, problem solving, discussion, explanation, debate, and brainstorming (Phelps & Damon, 1989). Interaction and collaboration among students are essential components of an active learning environment. Environments that promote student involvement in discussions about, explanations of, and brainstorming about relevant ideas help students construct a better understanding of those ideas (Goffin & Tull, 1985). Therefore, collaborative learning is necessary for the success of active learning teaching strategies.

Working collaboratively on problems has been found to be a valuable teaching strategy because the interaction between students generates conceptual conflicts and promotes conceptual change (Basili & Sanford, 1991; Lonning, 1993). Collaborative learning encourages students to work on problems and projects in teams, which promotes discussion, explanation, and debate among students. Computer simulations can be used as a tool to incorporate collaborative learning techniques. It was found that computer simulations can be used as a vehicle to promote communication and collaboration among group members (Krajcik, Simmons, & Lunetta, 1988; Otero, Johnson, & Goldberg, 1999). When students work in groups, they have opportunities to discuss and argue their ideas. Computer
simulations allow students to rerun a particular program and come to an agreement after reflecting on their ideas in group discussions. Communication requires students to reflect on and make explicit their conceptions. The process of communication can initiate conceptual conflicts and contribute to conceptual change. Therefore, conversation and interaction between students, promoted by computer simulation, can facilitate conceptual development. Kozma, Chin, Russell, & Marx (2000) conducted a study to investigate the impact of various graphic features in a computer simulation that helps students learn chemistry concepts. Overall, students using the computer simulations were found to have a significantly greater conceptual understanding of chemical equilibrium. However, no differences were found between groups using different graphic features. Kozma et al. (2002) argued that it took a variety of cognitive strategies for students to use a computer simulation effectively. In their investigation, students’ interactions and conversations while they engaged in inquiry using the same simulation was used to evaluate the impact of instructional use of computer simulations. Students’ inquiry was improved by constructing models of chemical reactions using computer simulations. Kozma et al. (2002) concluded that technologies and models need to be used within a social context to improve student learning (p. 136).

Wu, Krajcik, and Soloway (2001) studied how students use information in an on-line environment to understand chemistry concepts. Discussion between group members while using a computer simulation was found to help students understand chemical representations. In addition, individual differences such as level of engagement and the ways an individual interacts with group members were identified as having an impact on students’ learning with the instructional use of computer simulations. It is obvious that designing a computer simulation that is well adapted to each individual’s particular characteristics, learning
preferences, and needs would be complex. However, studying how students interact with their group partners and how they interact with the computer simulation could yield more in-depth information that would be useful in improving the quality of computer simulations and for planning how to use simulations instructionally to better benefit students who use them.

Recent research has investigated the impact of integrating different formats of computer technology such as on-line home assignments, computer generated graphics, and computer simulations with active learning strategies (Farnsworth, 2001; Skinner & Hoback, 2003). When used as part of an active learning strategy, computer simulations can be effective, especially if the program provides opportunities for users to discover the science concepts at their own pace (Horowitz & Christie, 2000; White & Frederiksen, 1998). A variety of research has found that computer simulations and animations help students learn scientific concepts in various disciplines (Kelly, 1997; Khoo & Koh, 1998; Kozma, 1991, 1994; Williamson & Abraham, 1995).

Information generated by a computer is commonly represented in static formats, such as graphics and images, and dynamic visuals, such as movie clips and animations. How an individual interacts with the computer simulations and how the visual representations affect an individual’s understanding need further investigation in order to match the pace that instructional computer technology is being improved.

*Representation of Information*

Text, symbols, and static graphics are commonly used to describe and represent chemical reactions. In addition, formulas and equations are frequently used to represent and communicate explanations about reactions and chemical phenomena. Visual materials are
commonly used in classrooms to help students understand the concepts and theories that seek to clarify chemical phenomena. According to dual coding theory (Paivio, 1986), information encoded in both visual and verbal formats is better remembered than that encoded in only one of these two formats. Paivio argued that information coded in either verbal or visual format could activate information coded in either formats. For example, the word "dog" can activate an image of a dog in the viewer's mind as well as the name of the dog if the viewer owns a dog as a pet. In chemistry textbooks, chemical reactions usually are presented in a format of equations and symbols accompanied by explanations and descriptions of the reactions.

Although images and graphics are commonly used to help students understand the chemical mechanism presented in the textbook, the static visuals may not provide sufficient information to help students understand the dynamic nature of chemical reactions such as the movement of electrons, the change of the color of chemicals during a reaction, and the particular position of atoms in a molecule. Dual coding theory suggests that if students can create and connect visual and verbal mental representations of the underlying and normally invisible chemical processes, they should develop a better conceptual understanding of chemistry. Over the years research has found practical evidence supporting the effectiveness of the use of instructional visual materials on learning (Burke, Greenbowe, & Windschitl, 1998; Dale, 1969; Levie & Lentz, 1982; Mayer & Sims, 1994; Rieber, 1989; Sanger, Brecheisen, & Hynek, 2001; Sanger & Greenbowe, 1997a, 2000). Learning with the assistance of visual materials was found to be superior to learning with text alone. Today's computer technology can generate high quality images and dynamic graphics using affordable personal computers. Computer simulations and animations can present visual representations of chemical processes and should facilitate conceptual understanding if
students process and encode such representations. Verbal representations include descriptions in words and in the form of symbolic equations; visual representations include both microscopic and macroscopic representations. Johnstone (1982) argued that, to learn chemistry concepts, students need to build knowledge and skills to comprehend chemistry reactions that are represented in microscopic, macroscopic, and symbolic levels.

*Computer Animation and Simulation*

A computer animation demonstrates a series of visual images that are displayed consecutively on a computer screen. Instructional computer animations are designed to provide visualizations of processes or events and to communicate abstract concepts and theories to students (Burke et al., 1998). Users of computer animation commonly receive visual information demonstrated by the animation passively. Computer animations, with their capability of demonstrating molecular level chemical reactions, have been found to be effective in helping students learn chemistry principles (Rieber, 1989; Sanger et al., 2001; Sanger & Greenbowe, 1997a, 2000). The processes of chemical reactions at the microscopic level become explicit when they are presented dynamically in a series of computer generated visuals. This feature of computer animation makes computer animations a powerful tool that can be used by instructors and science educators to help students build mental models of the molecular level of chemical reactions (Sanger, 2001).

Computer simulations accept input from users and demonstrate procedures or provide output using a series of animations. The procedures and output are calculated and demonstrated according to the specifications of the computer program. The combination of the procedure and output are used to present a context that is familiar to the users. Dale (1969) argued that in simulations, reality is represented in a highly modified fashion in order to
increase its accessibility for an individual’s understanding. In addition, computer simulations may increase students’ enthusiasm and motivation by giving them the chance to explore a replicated environment and conduct virtual experiments at their own pace. Computer simulations are considered to be valuable tools for allowing effects of changes to be seen in models before invoking the change in the real world (Marks, 1982). According to McGuire (1976), the use of a simulation is “placing the individual in a realistic setting where he is confronted by a problematic situation that requires his [sic] active participation in initiating and carrying through sequences of inquiries, decisions, and actions” (pp. 89-90). The incomplete information gained from computer simulations may compel students to make decisions based on the results and encourage them to solve additional problems. Therefore, the above-mentioned characteristics appear to promote students’ problem-solving skills.

As defined by de Jong and van Joolingen (1998), “a computer simulation is a program that contains a model of a system (natural or artificial; e.g. equipment) or a process” (p. 180). Gilbert and Priest (1997) defined a model is “a representation of an idea, object, event, process or system” (p. 751). The generated output of the model depends on the input from the user of the simulation (Thomas & Hooper, 1991; van Joolingen & de Jong, 1991). Therefore, one purpose of instructional simulations is to provide an opportunity for learners to discover properties of a model through the collection and analysis of data or information provided by the computer simulations.

Prior Knowledge

In instructional theory, the phrase “prior knowledge” refers to the knowledge that a person has at the beginning of a given learning episode or experience. Prior knowledge is commonly considered one of the most important variables that affects learning behavior and
results (Ausubel, 1968; ChanLin, 1999, 2001; Mayer & Sims, 1994). Gredler (1996) argued that students’ prior knowledge in both content and problem-solving skills might have an impact on the use of computer simulations that are designed to help students build their understanding of different content areas. She suggested that students’ prior understanding of the subject needs to be identified because the subject knowledge is necessary for students to manipulate variables or to conduct research using related simulations. She also suggested that it is helpful to identify the variables that are used in the simulations because the difficulty level of tasks increases according to the number of variables. Meanwhile, instruction on manipulating the variables prior to the use of simulations may be helpful to increase the usability of the simulations. Njoo and de Jong (1993) investigated the relationship between high school students’ prior knowledge and their understanding of physics concepts obtained or acquired in a computer simulation assisted learning environment. Their results indicated that students who had high prior knowledge test scores also achieved high posttest scores after completing the simulation-based computer lab. In addition, Njoo and de Joung (1993) found that levels of difficulty seem to be related to the levels of prior knowledge of the individual. Students with a high level of prior knowledge encountered less difficulty than those who with a low level of prior knowledge.

Among the research that showed positive relationships between prior knowledge and later performance, some research investigated the impact of prior knowledge on subsequent performance in different setups of learning activities. ChanLin (2001) compared the influence of eighth grade (labeled “novice”) and ninth grade (labeled “experienced”) students’ prior knowledge on their performance on a criterion referenced test of physics concepts. Students studied physical concepts in learning environments that provided different formats (text,
graphic, and animation) of information designed to help students learn. Overall, the treatment effect was significant among novice learners but was not significant among experienced students. However, novice students did not seem to benefit from the use of animation in learning. The researcher concluded that novices might not have had enough prior knowledge/experience to process information represented simultaneously in verbal and animated graphics. Therefore ChanLin (2001) suggested that careful consideration in the use of presentation formats was essential among novices.

Students have different needs with regard to learning in a system in which they need to make use of different representations of information. It is important to understand whether these needs are because of different experiences with the system or with different levels of knowledge. Therefore it is important to consider versatility in the design of a learning system in order that a variety of individuals benefit, rather than just a particular group of students. Realizing how students’ prior knowledge has an impact on their use of computer simulations in learning may contribute to the improvement of the design of the learning system and hopefully achieve the above-mentioned purpose.

*Computer Simulations Designed to Teach Electrochemistry*

The computer simulations used in this study were designed by a chemical education research group that is directed by a professor in the Department of Chemistry at a large Midwestern university. A computer application, Macromedia Flash MX™, was used to produce and modify the computer simulations. Macromedia Flash MX™ can be used to create animations and simulations that allow users to access applications either over the Internet or as stand-alone programs on operation systems such as Windows or Mac OS. The computer simulations used are available on the following web site:
Simulation 1: Activity Series of Metals

The "Activity Series of Metals" simulation was designed to demonstrate oxidation-reduction reactions between different metals and solutions containing different metal ions (Figure 1). An activity series is a list of substances ranked in order of relative reactivity. The activity series is a useful guide for predicting the products of metal displacement reactions. For example, placing a strip of zinc metal in a copper (II) sulfate solution will produce metallic copper and zinc sulfate, because zinc is above copper in the series. A strip of copper placed into a zinc sulfate solution will not produce an appreciable reaction, because copper is below zinc in the series and can't displace zinc ions from the solution.

As illustrated in Figure 1, students can choose from any of four metals, magnesium (Mg), copper (Cu), zinc (Zn), and silver (Ag), by clicking on a button to the left of the chemical symbol. When any of the four metals is selected, four metal strips made of that metal appear. By engaging the "Click here to put the metals into the solution" button, the metal strips are lowered into the solutions. Each solution contains one kind of metal ion. When the metal of the strip is more active than the metal that is in ionic form in the solution, colored shapes appear on the strips indicating ions from the solution have been reduced on the strips. The color of the strip was designed to match the color of the product of real reactions. The purpose of this simulation is to provide information for users to rank the activity of the four metals.
Use the mouse to pick a metal and test its reactions in the solutions.

- Mg
- Cu
- Zn
- Ag

Figure 1. Activity series of metals.

Simulation 2: Voltaic Cell

When users click on the “Activity 2” button (Figure 1), the scene of the simulation is switched to the “Voltaic Cell” simulation. The Activity Series of Metal simulation was combined with the Voltaic Cell simulation because these two topics are related and are studied during the same laboratory period. Voltaic Cell (Figure 2) simulates the settings of a real voltaic cell. Voltaic (galvanic) cells consist of two separate compartments called “half cells” containing electrolyte solutions and electrodes that can be connected in a circuit to a voltmeter placed between the two electrodes within the circuit. Oxidation takes place on the electrode called the “anode” where the atoms composing the electrode lose electrons which are then passed through conducting wires in the circuit. Reduction happens on the electrode called the “cathode” where ions in the solution receive/accept the electrons passed through the circuit by the anode. In order for oxidation and reduction reactions to occur, the circuit must be completed by connecting the two separate half cell compartments. The connection between the two compartments is accomplished by using a conducting medium, called a “salt
bridge," that allows ions to pass from one half cell to the other. The mechanism and function of the salt bridge are ignored in this simulation in order to allow students to focus on the concepts of oxidation-reduction within voltaic cells.

There are two sets of buttons on both the right and left sides of the screen. Each set of buttons is composed of two buttons labeled either “Metal” or “Solution.” A list of buttons and metal symbols of copper (Cu), zinc (Zn), and silver (Ag) appear when students click on the “Metal” button. A list of buttons and formulas indicating the solute in each solution [copper sulfate (CuSO₄), zinc sulfate (ZnSO₄), and silver nitrate (AgNO₃)], appear when students click on the “Solution” button. A metal bar appears and is connected to the terminal when students click on any of the buttons next to the metal symbol. The solution selected appears in the beaker when students click on any of the buttons next to the formula of the solutions listed. Students can determine the two electrodes (anode and cathode) of the cell and solutions in the beakers by selecting the buttons of metals and solutions on the sides. By clicking on the power switch of the voltmeter, animations of the reactions in both beakers
take place. The movement of electrons through the circuit, the movement of ions in the solutions, and the exchange of electrons between ions and atoms in the beakers are illustrated in the animations. Note that the animation of electron movement takes place only when the metals and solutions are correctly set up. For example, if a student selects zinc metal in a copper sulfate solution rather than a zinc sulfate solution, an animation shows copper ions moving toward the zinc metal bar and depositing on the metal bar while the zinc metal bar dissolves and zinc ions are passed into the solution. This reaction occurs because zinc is more active than copper. In such a situation, no electron movement is displayed because the exchange of electrons happens only inside one of the beakers.

If the cell is correctly set up, the resulting voltage of the cell is calculated by the program on the basis of the standard reduction potentials of the metals comprising each electrode, and the value of the voltage is shown on the display panel of the voltmeter. The movement of ions in both half-cell solutions and electrons in the circuit is shown on the screen when students turn on the voltmeter by clicking on the power switch (Figure 2).

**Simulation 3: Voltaic Cell (Electromotive Force) and Concentration**

The third simulation was developed based on the second simulation (Voltaic Cell) but gives students the additional options of changing the molarities of both solutions (Figure 3). The electromotive force (EMF) is the maximum potential difference between two electrodes of a galvanic or voltaic cell. This quantity is related to the tendency of an element, compound, or ion to acquire or release electrons. The EMF of an oxidation-reduction reaction in a voltaic cell is determined not only by the type of reaction, but also by the concentrations of the reactants and products (i.e., the reducing agent and oxidizing agent). The voltage of the cell varies according to the differences of molarities between the solutions in the half cells.
This simulation shares the same structure and interface as the Voltaic Cell simulation. In order to help students explore the impact of concentration differences on the resulting voltage, the simulation provides additional options for users to change the molarities of metal ions in each solution. Also, a table that lists the standard reduction potentials of different metals appears when students move the computer mouse over the button labeled “$E^0$ of Metals” on the lower right of the screen (Figure 3). The table was designed to provide users the values of standard reduction potentials of the metals so that they can predict the resulting voltage of the cell. In addition, two buttons labeled “Molecular Level Reaction” appear on the beakers when the animation of electron movement ends. Clicking on the buttons causes a window to pop-up and illustrate the molecular level reaction between the metal atoms on the strip and metal ions in the solution (Figure 3).

![Voltaic Cell](image)

*Figure 3. Voltaic cell (electromotive force) and concentration.*

*Simulation 4: Quantitative Aspect of Electrolysis*

Electrolysis is a process by which electrons are forced through either a chemical cell or a power supply, thus causing a chemical reaction. The positive charge usually attracts electrons, and the electrode providing electrons is called a cathode because reduction takes
place on it. The “Electrolysis” simulation borrows the mechanism from the Voltaic Cell series simulations. However, additional controls and information are added to the power supply, which functions as a voltmeter in the Voltaic Cell and Voltaic Cell (Electromotive Force) and Concentration simulations. Therefore, the power supply in this simulation not only supplies energy but also provides readings of the current and voltage of the electrolysis cell.

Since the power supply shows the values of the voltage produced in the Voltaic Cell simulation, it also displays the voltage applied to the electrodes that drive the electrolysis reaction and the resulting current in the electrolysis simulation. The power supply also has an indicator that displays the amount of time the voltage will be applied to the cells. Students can control the amount of time for the electrolysis reaction (Figure 4). Because an electrolysis reaction requires voltage to drive the electrons and force the reaction, users are given the opportunity to set and modify the value of the voltage, current, and length of time for the reaction. Students choose the values of the voltage and time by using the mouse to drag the sliders below each display panel on the power supply that shows the values (Figure 4). When students set the current, the value of the voltage is calculated by the computer program and vice versa. However, when the simulation operates, the time selected by the students moves faster than real time does. This feature allows the students to observe the effects in a shorter time than the reaction actually should take and allows users to explore the simulation with more situations per unit of real time than users could do with physical equipment. The choices available for the metal bars for the electrolysis reaction on both electrodes are nickel and iron, and the choices for solutions in the bath for reaction are nickel (II) nitrate (Ni(NO₃)₂) and iron (II) nitrate (Fe(NO₃)₂). The mass of the metal bar on either electrode can be modified by dragging the slider under the names of the metals in this simulation (Figure 4). The mass
of each metal bar changes according to the position of the slider. This feature is designed to help users compare the change of the masses on either electrode at the end of the reaction. All the sliders in this simulation were designed so that the respective values increase as the slider is dragged toward the right. As the simulation runs, the boxes as well as the accompanying the sliders are hidden and the options for the simulations are disabled to avoid interruption of the program's algorithm. Two additional boxes colored in blue (Figure 4) are designed to display the changing masses of metals bars on each electrode; these two boxes are not hidden while the reaction proceeds.

The minimum voltage for the electrolysis to take place is calculated by the program according to the standard reduction potentials of the metal strip on the anode. A warning window pops up when the voltage a student selects is lower than the required voltage for the reaction to take place (Figure 5).

Similar to the other simulations, animations of the microscopic level of the reactions such as the movement of ions in solutions, the metal deposits on the metal bar of the cathode,
and the movement of electrons in the circuit is illustrated according to the users' choices of metals and solutions. The computer simulations were designed to help students learn electrochemistry by visually representing the information at both macromolecular and micromolecular levels. A better understanding of how students responded to the simulations and how the computer simulations affected the interactions among learners would be beneficial for designers and science educators to improve the design of computer assisted learning activities. This better understanding would help designers create computer simulations then can help learners construct their knowledge of electrochemistry. As a result, the purposes of this study are to understand within the framework of an active learning strategy:

1. How students interact with computer simulations that were designed to teach electrochemistry, how computer simulations promote interactions between peers, and how these interactions affect student learning?

Figure 5. The warning window.
2. How students' prior knowledge as measured by total points earned from a chemistry diagnostic test given at the beginning of their first semester general chemistry course affect the ways they interact with the computer programs.

3. How students with different levels of prior knowledge interact with their peers and how the interactions affect students' understanding of chemistry concepts with the help of computer simulations.

**Methodology**

*Participants and Design*

In order to achieve the research purposes, which were to examine in-depth how students interacted with each other and with the computer programs, a qualitative case study research design was employed. The target population for this study was freshman students, typically 18 and 19 years old, at a large Midwestern university in the U.S. Electrochemistry is one of the topics included in a second semester introductory chemistry course. Studies have found that students in the same gender group have better interactions than students in mixed gender groups when learning collaboratively (Strough, Swenson, & Cheng, 2001). Therefore, participants in this study were 6 female volunteers selected from 47 students who had volunteered for a larger study. A purposive sampling procedure was employed. The impact of gender differences on students' interactions and learning have been studied over the years (Hakkarainen, Jarvela, Lehtinen, & Lipponen, 1998; Hakkarainen & Palonen, 2003; Strough et al., 2001; Underwood, Underwood, & Wood, 2000; Webb et al., 1995). However, the results of these studies are mixed and still under debate. In order to remove the interference of gender differences, only female students were selected. The collaborative tasks relied heavily on verbal skills, where females often tend to outperform males (Hyde & Linn, 1988).
In addition, research on computer-assisted learning has found that female students are more willing to share their cognitive achievement and are more interested in collaborative learning than male students (Hakkarainen et al., 1998; Underwood et al., 2000). With regard to data collection, the present study sought to take advantage of the rich interactions between members of female groups and focus on the findings that were consistent to the research purposes.

Because the students’ point totals from the prerequisite course were used as a measure of their prior knowledge, only students who had completed the prerequisite introductory level chemistry course were included in the present study. Prior knowledge may affect how students interact with peers and with the computer simulations. For this case study, pairs of students who had already chosen to work together were selected based on their prior knowledge. Pairs were selected by examining each member’s ACS scores (described in the “Instruments” section of this paper). The first pair of students each had test scores that were higher than the average score of all 47 participants. The second pair of students was composed of one student whose test score was higher than average and the other whose test score was lower than average. The third pair of students was composed of students who each had test scores that were lower than the average score.

Two students comprised each group. Students in each group were labeled using their group number, “A” or “B.” For example, one student in Group 1 was labeled as Student A (G1SA) and the other as Student B (G1SB) in the transcript excerpts below. Group 1 was composed of two students whose ACS scores were both at least 15 points higher than the average ACS score of all the students registered for the course. Students in this group were labeled G1SA and G1SB. Group 2 was composed of one student (G2SA) whose ACS score
was 15 points higher than the average of all the students' scores and one student (G2SB) with an ACS score that was 10 points lower than the average score. Group 3 was composed of two students (G3SA and G3SB) both of whom had ACS scores that were 10 points lower than the average ACS score.

The data collected included the students' answers to tutorial and test questions, conversations between peers, and video- and audio-taped interactions between group members and with the computer simulations. In addition, students' interactions with and activities conducted while using the computer simulations, such as mouse movement, login time, and mouse clicks, were recorded by the computer program and saved in a database.

**Instructional Materials**

**The Nature of the Course**

The course for this study was the second semester course of a two-semester course sequence in introductory chemistry for non-major students. The first semester class was a prerequisite to the second semester class. The two-course sequence explores chemistry with an emphasis on concepts, problems, and calculations, and focuses on principles and quantitative relationships, stoichiometry, chemical equilibrium, acid-base chemistry, thermochemistry, rates and mechanism of reactions, changes of state, solution behavior, atomic structure, periodic relationships, and chemical bonding. Electrochemistry, acid-base equilibria, thermodynamics, nuclear chemistry, and descriptive topics (non-metals, transition metals, coordination compounds, organic compounds, polymers, biological molecules) are the topics that are also covered in this course.

Lectures were given twice each week in two 1-hour periods. Unannounced quizzes were given in lecture. Questions selected from chapters in the textbook and covered in the
lecture were assigned to students each week. Students were required to turn in their assignments during a recitation meeting that was held each week to help students with the assigned questions. During each recitation meeting, teaching assistants helped students to understand the chemistry of the assigned homework questions. Students were able to discuss with the teaching assistants methods of problem solving and the nature of the presented concepts and principles, and to ask questions. The teaching assistants also took turns helping students in an organized help center, a classroom in which students were able ask questions of teaching assistants.

Three 1-hour examinations were given during the semester to test students' understanding of concepts and principles covered by the lecture. A 2-hour instructor-written comprehensive final examination was given at the end of the semester. Students' grades were based on the accumulated points from the 1-hour examinations, the final examination, homework assignments, and lecture quizzes.

The Laboratory

The lecture course was a prerequisite or co-requisite for the laboratory. Students needed to either have taken the lecture course or be taking the lecture course in the same semester to be eligible to take the laboratory. Students needed to attend a 3-hour laboratory period each week. Each week in the laboratory, they conducted experiments that involved the same concepts and principles that were covered by that week's lecture. Teaching assistants facilitated each laboratory section, briefly explained the principles and procedures of the experiments, answered questions, and graded students' laboratory reports. Each laboratory period, students were also required to find the "Material Safety Data Sheet" (MSDS) on the chemistry department's web site for the substance(s) with which they would be working and
answer a few short questions as the safety assignment for each laboratory. Two laboratory practical examinations were given to students to test their understanding of the principles, concepts, experimental procedures, and techniques of each laboratory experiment. Practical examinations were given at the middle and at the end of the semester. Grading for the laboratory was based on the points earned from laboratory reports (70%), safety assignments (10%), and practical examinations (20%).

Textbook

The textbook used in this course was *Chemistry: The Central Science* (Brown, LeMay, & Bursten, 2000). It consists of 25 chapters covering chemistry concepts and principles that are described in the “The Nature of the Course” section of this paper. Static illustrations of macroscopic and molecular levels of chemical reactions, natural phenomena, and equipment are used in the book to help students visualize the textual content that describes chemistry concepts. An “Exercise” section at the end of each chapter serves to help students review their understanding of the content and consists of questions that are categorized according to the principles covered in the chapter. Students’ homework assignment questions were selected by the instructor from the questions in this section.

Laboratory Manual

The laboratory manual used was edited by the laboratory supervisor of the chemistry department and is composed of 16 topics covering the same concepts as the lecture content. Basic chemistry concepts and principles are introduced at the beginning of each topic followed by a procedure section for the experiment. A list at the end of each topic functions as the checklist for the teaching assistant to grade student laboratory reports (Appendix C). Eight items of the list are used to check whether students have completed all the required
sections of their report such as title, purpose, procedure, data/observations, balanced equations, calculations, results, and discussion. Two items work as an evaluation of students’ preparation and understanding of the overall laboratory. Students were required to tear out the list and staple it to their laboratory report before turning in their report.

*Computer Simulations Used by the Treatment Group*

In this study, the four computer simulations described in the introduction section were used as tools to help students learn electrochemistry. In addition, all the simulations were connected to a database that stored student input as the programs were used. The database stored the following variables:

- The time a user initially logged on to the system.
- The length of time users used the system. The difference between time logged in and time logged out was identified as the length of time users used the system.
- Records of students’ mouse movements (listed below) were used to eliminate the “dead time” during which students were not using the simulation but still logged on.
- The students’ mouse movements. The positions of students’ cursors were recorded by the program every 5 seconds. The number of seconds when there was no change in the position of the cursor was indicated as “dead time” in simulation usage.
- The metals selected for testing the metals’ reactivity.
- The metal selected for the electrodes.
- The reactants chosen for the solutions.
- The molarities of the solute in the solutions.
- The values of voltages applied.
- The values of current generated by the respective voltage.
• The time applied for the electrolysis reaction.

• The final mass of the product.

The data was temporarily stored on the user’s computer by the computer simulation and was then submitted to the server when the users clicked on the “Click here when you are done” button below the title of the simulations (Figures 2, 3, and 4). The researcher monitored students’ activity by directly observing the students while they were using the simulations. The researcher advised students to click on the “Click here when you are done” button whenever they forgot to do so as they finished the simulations.

_Tutorials for the Simulations_

Three tutorials were developed to assist students manipulate the simulations (Appendix D). The tutorials were handed out to students when they started to use the simulations. In general, these tutorials served as the manual for using the computer programs and provided the questions to track or monitor students’ understanding of the concepts behind the computer programs as well. The first part of each tutorial guides students to set up the equipment of the simulated experiment and contains instructions such as “Start the software and construct a zinc-copper electrochemical cell using 1.0 M Zn\textsuperscript{2+} and 1.0 M Cu\textsuperscript{2+} solutions.” The instruction is followed by questions that probe students’ understanding of the topic covered. For example, a question such as “For the voltage that you are measuring, is this \(E^\circ_{\text{cell}}\) or \(E_{\text{cell}}\)? Please explain” follows the above-mentioned instruction and collects students’ background knowledge regarding electrochemistry.

Questions in the second part of each tutorial are more open-ended, for example, “Construct an electrochemical cell for which the EMF of the cell is greater than +1.10 V. Before doing the simulation, predict the EMF of the cell.” This question provides limited
information for students; therefore they need to use their prior understanding of chemistry knowledge to explore the concepts on which the simulation is based and carry out the task.

*Equipment and Setting*

The study was conducted in a chemistry laboratory in which students who were taking the course usually conduct their laboratory activities. The computer simulations were installed and ready for use in the laboratory on two laptop computers with Internet connections. Students needed to complete their normal laboratory activities as well as the computer simulations in a 3-hour period. Therefore, in order to save participants’ time, a web page with the simulations embedded was opened and ready for use. Two video camcorders were also set up in the laboratory to record students’ interactions with each other as well as their interactions with the computer programs.

*Instruments*

*Prior Knowledge*

Students’ total points gained from a chemistry diagnostic test, called the “ACS California Chemistry Diagnostic Test” (ACS diagnostic test), taken at the beginning of the prior semester also were obtained as a measure of the students’ prior knowledge of basic chemistry concepts and laboratory practical skills. The test provided a measure of students’ chemistry background before they enrolled in the prerequisite (first semester) course. The test was developed by the Division of Chemical Education of the American Chemistry Society (ACS) and has been released annually since 1934. The ACS diagnostic test was designed to be used as either an end-of-course test or placement exam for high school or higher level students. It was designed to assess students’ knowledge in the fields of general chemistry, organic chemistry, analytical chemistry, physical chemistry, inorganic chemistry,
biochemistry, polymer chemistry, basic mathematics, and high school chemistry. The coefficient alpha of the test is 0.87 based on a sample of 4023 students as reported in Karpp's (1995) study. The high value indicates the test is internally consistent.

The ACS diagnostic test was given to students who enrolled in the prerequisite course at the very beginning of the course to evaluate their general chemical background and mathematic ability. The questions used for this diagnostic test were published in 1997. Forty-four multiple-choice items were used in the diagnostic test. Thirty-three items tested students' chemistry background and the other 11 items tested students' basic mathematic abilities. The ACS diagnostic exams are "closed" exams. Because copying the test items is forbidden, therefore, only the cover page of the test booklet is listed in Appendix E. Questions similar to ACS test item such as "If water is allowed to evaporate from an unsaturated saltwater solution, how will the concentration of the solution change?" ask students to identify substances using their physical properties. Items such as "When bonded with sulfur, which element will most likely form an ionic compound?" assess students' understanding of the structure of compounds, relating bonding and molecular geometry to chemical and physical properties. A table of composite norms and test statistics reported by the Division of Chemical Education of the ACS is listed in Appendix F.

Achievement

The second laboratory practical exam contained 13 out of 14 items that relate to electrochemistry. These items assessed students' knowledge of electrochemistry concepts as well as their laboratory skills (Appendix B). The points assigned to each item varied, and the total possible score was 35 points. The laboratory practical exam was composed of multiple choice questions, open-ended questions, and diagrams that required students to identify
electrodes, half cells, and flow of electrons. Students' written explanations for the open-ended questions of the laboratory practical exam were collected and used to compare with their interactions with their peers and with the computer simulations.

Procedure

The instructional unit and assessments took up three laboratory periods in three consecutive weeks, a total of nine hours during three laboratory sections. Students were asked to log on to a server on an Internet web page in order to use the computer simulations. As noted, logging on allowed data from the use of the simulations to be recorded in the database running on the server (Figure 6) and to be accurately associated with the correct student.

![Login window](image)

Figure 6. Login window.

Printout tutorials including instructions, tasks, and questions were handed out to the participants when they started to use these simulations. The activities described above required participants to answer these questions from their observations and from the data demonstrated by the computer simulations.
Week 1: Recruiting Volunteer Participants

Announcement of a study in which participants could be involved to learn with computer simulations was made in the laboratory one week prior to laboratory sections that focused on electrochemistry concepts. Informed consent forms were given to students in the laboratory and only students who agreed to participate were selected for this study. Altogether, 52 students signed up to use computer simulations during their regular laboratory activities; however, only 47 students accomplished all the required activities.

Week 2: Oxidation-Reduction Reactions and Electrochemistry

All the students in the laboratory period tested different combinations of actual voltaic cells. The students placed two different metal strips into sulfate solutions that contained the same metal ions in wells and used filter paper rinsed with sodium nitrate (NaNO₃) solution as a salt bridge to connect the two half cells. Students were guided by the teaching assistant and the lab manual to repeat the experiment and measure the resulting voltages obtained when different metals and solutions were used. In each experiment, students used copper metal and its sulfate solution as one of the half cells but used different metals and their sulfate solutions as the other half cell. Prior to the first computer simulation activity, the participants were asked to find a partner who had also agreed to be in the study so that they could work on the simulation together. The partners of each group needed to be the same for the next two laboratory periods when they would use the subsequent simulations. During the lab, each pair group needed to use part of their laboratory time to access the Activity Series of Metals simulations. Because this laboratory covered both topics of oxidation-reduction and the voltaic cell, a button labeled "Activity 2" was included in the Activity Series of Metals simulation that would reveal the Voltaic Cell simulation when it was clicked. Students first
followed the instructions on the tutorial to test each metal with different solutions and ranked
the metals according to their observations. In the second simulation, students were told to
connect a zinc-copper cell and answer questions according to their observations. Students’
activities with the computer simulations were video taped and their conversations were audio
taped. Students were asked to write down their names, laboratory section, and the current date
and time on the worksheet when they started the simulation so their video and audio taped
interactions could be identified. Each group was required to turn in their tutorial with answers
based on their observations from the simulations after they accomplished the tasks.

Week 3: Voltaic Cell EMF

The actual laboratory in Week 3 focused on the influences of concentrations of each
of the half cell solutions on the resulting voltage of the cell. All the students worked in groups
of two and were required to prepare solutions of copper (II) sulfate (CuSO_4) and zinc sulfate
(ZnSO_4) in concentrations of 1.00M, 0.100M, 0.0100M, and 0.00100M. Then students placed
copper and zinc metals in sulfate solutions containing appropriate metal ions. The half cells
were then connected with filter paper rinsed with sodium nitrate (NaNO_3) solution, which
worked as the salt bridge for the cell. The participants measured and recorded the different
voltages produced by the different molarities of the solutions.

The simulations illustrated the same ideas as the actual laboratory activities but
provided additional options for changing molarities of the solutions in both the anode and
cathode half cells. As in the previous laboratory, each group was required to turn in their
tutorial with answers based on their observations from the simulations after they
accomplished the tasks.
Week 4: Electrolysis

This section of laboratory was the last laboratory period for the course. In the actual laboratory activity, students were asked to connect a copper strip as the anode and a stainless steel strip as the cathode with a power supply. The strips were placed into a copper (II) sulfate (CuSO₄) solution. In this task, copper ions in the solution would be reduced on the stainless steel strip when the power supply was turned on. Students were instructed to record the time, current, and voltage applied for the electrolysis reaction and to measure the change of the masses on both electrodes.

Students participating in this study needed to work in their pairs on the Electrolysis simulation. This simulation illustrated the same ideas as in the actual laboratory activities, but provided choices of nickel and iron metals rather than copper and stainless steel as the metal strips for the anode and cathode. Accordingly, the choices of the ions in solution were nickel and iron rather than the copper ions used for the laboratory exercise. As mentioned in a previous section, only when the voltage was set higher than the minimum necessary reaction voltage could the animation begin. The differences between the mass before and the mass after the electrolysis process of the metal strips were calculated by the program. Students were instructed to record the results of their observations on the tutorial worksheet. Each pair was required to turn in their tutorial with answers based on their observations.

Week 5: Laboratory Practical Examination

All the students took the laboratory practical exam during this week.

Week 7: Comprehensive Final Examination

All the students took the instructor-written final comprehensive course exam during this week.
To answer the research questions, classroom observations, in-class field notes, student answers for the open-ended tutorial questions, participants' responses toward the computer programs, which had been recorded in the database, and the transcribed student interactions from video and audio taped data were organized and analyzed.

The transcriptions of student interactions were categorized and organized based on constant comparison principles (Strauss & Corbin, 1990). Using the constant comparison method, categorizing and refining categories was repeated until patterns and themes were identified. During the process of data analysis, several of the data sources were used to accomplish triangulation of this study. Such type of triangulation has been identified by Denzin (1978) as "data triangulation." Students' answers for the final examinations and for the open-ended tutorial questions, and the database information of students' usage of the computer simulations demonstrated the students' learning process over time. Therefore, those data were used to triangulate the findings of the video transcripts. For example, students' trials for the settings of the computer simulations and the answers for the tutorial questions were examined as to whether they were consistent with students' responses toward the computer simulations and their predictions for the tasks on the worksheet.

Based on the constant comparison method (Strauss & Corbin, 1990), data that started to emerge from students' conversations were coded in a sequence of analytical steps. The transcriptions were first analyzed line by line to understand the connections among ideas, incidents, and themes, and to sort them into proper categories based on the connections (Table 1).
As the process of categorizing and refining continued, analytical domains were derived from the initial categories by delineating properties and dimensions (Table 2). For example, in the difficulties and confusions domain, properties include computer simulation

Table 1

*Initial Categories Identified in the Data*

<table>
<thead>
<tr>
<th>Category</th>
<th>Emerging incidents, ideas, and themes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mistake on:</td>
<td>Using computer simulations; Answering questions; Setting up experiments; Making predictions</td>
</tr>
<tr>
<td>Difficulty of:</td>
<td>Setting up experiment; Making predictions; Reaching conclusions; Following instructions; Operating the computer simulations</td>
</tr>
<tr>
<td>Assistance from:</td>
<td>Teaching assistant; The researcher; Textbook; Class notes; Peers; Computer simulations</td>
</tr>
<tr>
<td>Comment on:</td>
<td>The computer; The simulations; The Tasks</td>
</tr>
<tr>
<td>Agreement/Disagreement on:</td>
<td>The use of simulations; The simulation results; The answers; Predictions</td>
</tr>
<tr>
<td>Confusion of:</td>
<td>The computer simulations; The handout questions; The instructions; The tasks</td>
</tr>
<tr>
<td>Expression of Understanding:</td>
<td>Spoken description; Gesture; Written description</td>
</tr>
<tr>
<td>Reference to:</td>
<td>Formulas; Chemistry principles; Textbook</td>
</tr>
</tbody>
</table>
Table 2

*Analytical Domains Derived from Coding*

<table>
<thead>
<tr>
<th>Analytical Domains</th>
<th>Dimensions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Properties</td>
<td></td>
</tr>
<tr>
<td><strong>Visual Aid</strong></td>
<td></td>
</tr>
<tr>
<td>Macroscopic level</td>
<td>Color change during reactions; Apparatus for experiments; Options for setting up experiments</td>
</tr>
<tr>
<td>Molecular level</td>
<td>Movement of electron; Movement of molecules</td>
</tr>
<tr>
<td><strong>Confusion/Difficulty</strong></td>
<td></td>
</tr>
<tr>
<td>Computer simulation</td>
<td>Navigation of the programs; Misunderstanding of the results; Conflict with predictions</td>
</tr>
<tr>
<td><strong>Task</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Making predictions; Making conclusions;</td>
</tr>
<tr>
<td><strong>Interactions</strong></td>
<td></td>
</tr>
<tr>
<td>With computer simulations</td>
<td>Making new trials; Attitude toward the simulations; Questioning the results</td>
</tr>
<tr>
<td>With group members</td>
<td>Reaching agreement; Arguing with understanding; Collaboration;</td>
</tr>
<tr>
<td><strong>Problem-solving Strategies</strong></td>
<td></td>
</tr>
<tr>
<td>Help seeking</td>
<td>Resource from group members; Resource from outside of the group; Resource from the simulations</td>
</tr>
<tr>
<td>References to simulations</td>
<td>From macroscopic level of representation to molecular level of representation</td>
</tr>
</tbody>
</table>
Table 2 (continued)

<table>
<thead>
<tr>
<th>Involvement of Prior Knowledge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Understanding</td>
</tr>
<tr>
<td>Misconceptions; Description of electrochemistry principles; Trace of reasoning</td>
</tr>
<tr>
<td>Memories</td>
</tr>
<tr>
<td>Memories of formulas and equations; Memories of rules and principles</td>
</tr>
<tr>
<td>Mathematical skills</td>
</tr>
<tr>
<td>Algorithm; Calculation; Solving algebra</td>
</tr>
</tbody>
</table>

and task. The property of the difficulties and confusion encountered regarding accomplishing the tasks varied from making predictions to making conclusions.

As categorizing and refining went on, three major themes emerged, and subcategories of each theme were organized according to their contribution to the main themes (Table 3). The patterns and themes were used to identify the ways students interacted with computer simulations and with their group members and their understanding of electrochemistry concepts.

Results

Three major themes, described in Table 3, emerged from the qualitative analysis. These themes were labeled: (a) Using Simulations as Tools for Visualization—simulations were used as tools for students to visualize the molecular level of chemical reaction; (b) Solving Problems with Simulations—the problems here representing the “set” problems in the worksheets accompanying the simulations; and (c) The Impact of Prior Knowledge—this theme was categorized to present the effect of students’ prior knowledge, which in this case
Table 3

*Main Themes and Subcategories*

<table>
<thead>
<tr>
<th>Themes</th>
<th>Subcategories</th>
</tr>
</thead>
<tbody>
<tr>
<td>Using Simulations as Tools for Visualization</td>
<td>Visualization of chemical reactions</td>
</tr>
<tr>
<td></td>
<td>Interference and misunderstanding caused by the simulations</td>
</tr>
<tr>
<td>Solving Problems with Simulations</td>
<td>Conflicts caused by the simulations</td>
</tr>
<tr>
<td></td>
<td>Promoting discussions</td>
</tr>
<tr>
<td></td>
<td>Problem-solving strategies with the use of simulations</td>
</tr>
<tr>
<td>The Impact of Prior Knowledge</td>
<td>Impact on interaction with group members</td>
</tr>
<tr>
<td></td>
<td>Impact on solving problems with simulations</td>
</tr>
<tr>
<td></td>
<td>Impact of attitude toward simulations</td>
</tr>
</tbody>
</table>

means students' prior chemistry understanding. The presentation of the results of this study are organized around these three themes and presented in the form of case examples or short studies.

*Using Simulations as Tools for Visualization*

Computer simulations are capable of providing dynamic visuals that represent the molecular level of chemical reactions and macroscopic level of chemical phenomena. The following section presents examples of how the simulations offered visual aids in helping students understand electrochemistry and accomplish their tasks. However, some of the features of the simulations and the design of the learning activities were found to interfere
with students' usage of the computer simulations as well as their interpretation of the visual information. Examples illustrating such issues are also presented in the next section.

**Visualization of Chemical Reactions**

In Activity 1, four metal strips that were made of the same metal appeared when students selected one of the metal strips (magnesium, copper, zinc, and silver). When students clicked on the “Put metal strips into solution” button, the strips were immersed into four beakers, each containing a different solution of ions of one of the four metals. Physical change (e.g., metal ions in the solution became atoms and deposited on the strips) took place when the metal of the strip was more active than the metal ions in the solution. The computer animation demonstrated macroscopic level reactions on metal strips. Members of Group 1 took the advantage of the animated results and easily ranked the reactivity of the metals according to the number of reactions that took place on the metal strips.

G1SA: When I put magnesium in the solutions . . . something comes out on the strips, so it looks like all of them react with magnesium.

G1SB: So Mg reacted with ZN, CU, AG . . . but not magnesium nitrate . . . . OK, let’s do it.

G1SA: Copper . . . OK.

G1SB: It only reacts with silver nitrate.

The animation visually gave the students the information that made the ranking for the activity series of the four metals (magnesium, zinc, copper, and silver) explicit. Therefore, the group members answered the first question based on the visual information they received from the computer simulation.
Group 3 also made use of the animation to accomplish this task and rank the activity of the four different metals. With almost no discussion, Group 3 accomplished the task by trying all the metals and then ranked the metals by their activities according to the visual results provided by the computer program.

G3SA: Magnesium reacted with zinc, copper, and silver [writing] . . . . Want to try another one?

G3SB: It [copper] only reacted with silver.

G3SA: [Writing] . . . AGNO three . . . OK.

G3SB: Zinc reacted with copper and silver.


OK . . . [reading instruction] which of the four metals you tested is the most reactive? . . .

G3SB: It’s . . . magnesium . . . because it reacted with the most substances.

G3SA: Silver is the least reactive . . . [writing]

This simulation demonstrated the results of chemical reactions at the macroscopic level; the students’ visual experiences with the simulation were similar to students’ experiences in the laboratory activities. However, the setup for students’ real life experiment required them to test the metals in a 48-well culture plate. Students needed to place one metal in one solution at a time and record the results for research questions. In the computer simulation, all four reactions occurred on the screen at once. The computer simulations provided the results as visuals that were easier to compare and more organized than the results in the real life experiment. This feature seemed to help students rank the metals’ reactivity.
Like the students in the other groups, students in Group 2 had no difficulty identifying the most and least reactive metals tested in this computer simulation. In this activity, the visual information provided by the computer simulation served as evidence that confirmed student G2SA's prediction, "I guess it will react with silver but nothing else . . . . Yep!"

However, it seems that student G2SA could easily visualize the chemical reactions with her mental model regardless of the visual assistance from the computer simulation. She expressed her feeling about the computer simulation as, "If you break the computer, it doesn't matter because we are doing exactly the same thing."

For G2SA, the macroscopic level of animation in Activity 1 did not seem to make much difference in understanding the reactivity of different metals compared to the activities in the real laboratory situation. The researchers' field notes indicated that G2SA finished the real life experiment before she started to use the simulation. It is possible that she could predict the results demonstrated by the animation by relating it to the experiment she had already done.

In addition to its similarity to a real laboratory at a macroscopic level, the computer simulation has the ability to provide a visual presentation of the molecular level of reactions. Many students have difficulty conceptualizing or visualizing microscopic or molecular levels of interaction. In Activity 2, students needed to set up a voltaic cell by choosing metal strips and solutions for each electrode. Animations of molecular level reactions and electron movement were demonstrated when students clicked on the power switch of the voltmeter. The computer animations were designed to help students visualize the molecular level of reactions. For example, the demonstration of the movement of electrons in the circuit gave students a clue for identifying whether the strip lost or gained electrons.
G1SB: Mark the species that loses electrons . . .

G1SA: Zinc loses electrons and they flow through here [pointing at the screen following the direction of electron flow].

The movement of the electrons and the generation of ions demonstrated by the computer simulation guided students in accomplishing their tasks.

G1SA: [reads instructions] Write down the appropriate oxidation half reaction under the . . .

G1SB: We need to find out the oxidant.

G1SA: But . . . isn’t that we have . . . zinc? [looks back to the blackboard for answer] . . . I don’t know I can see . . .

G1SB: Yeah, it is. It’s right here [points at the screen, the movement of electrons stopped but the zinc ions generated from reaction moved around in the solution], ZN 2 plus. ZN 2 plus, plus 2 E minus . . . [writes down the half reaction]

The molecular level of animations helped Group 1 visualize the mechanism of a voltaic cell and identify the anode and cathode of the electrochemistry cell.

G1SB: The electrons are moving through the wire . . . .

G1SA: So CU. Because the atoms are all going around.

G1SB: No, the oxidation is actually done right here.

G1SA: Is that where it occurs? When we see these are all going to that one [copper ions going toward the copper strip] and these are all going that way [zinc atoms becoming zinc ions and move toward the solution] [points at the screen] and that’s because electrons are all going here [copper strip].
G1SB: Yeah... but the ZN is losing electrons so that’s where oxidation occurs.

As G1SA’s statement illustrates, the molecular level animation demonstrated the movement of electrons that gave students the idea that electrons moved from the zinc electrode to the copper electrode. In addition, the animation showing the oxidation (losing electrons) of the zinc atom and reduction (gaining electrons) of copper ions supported student G1SB’s reasoning while student G1SA had difficulty identifying the anode and cathode of the cell. However, G1SB corrected G1SA’s conclusion by pointing out the principle that ZN was oxidized because it loses electrons while G1SA expressed her thought of identifying the anode of the cell.

In Group 2, the direction of electron movement was used to verify the direction in G2SA’s mental model of the voltaic cell for identifying the electrode that was reduced:

“Uh... it’s not [spontaneous], because the electron was going that way? [points to the screen]... No, what’s being reduced here? [checks answer]... Copper is reduced. CU 2 plus... [points at the attached table]... It is spontaneous.”

The molecular level representation of an oxidation-reduction reaction seemed to make explicit the process of electron transfer between oxidizing and reducing agents and helped students consolidate their mental model of an electrochemical cell. The visual information from the computer animation helped student G2SA make a connection with her mental model of the voltaic cell: “The electrons are going from... zinc metal... towards the copper. So the zinc is going to be in 2 plus on the right hand and the copper is going from 2 plus to copper solid.”

The movement of the electrons helped G2SA visualize the exchange of the electrons between metal the atoms and ions. As a result Group 2 wrote their half reactions based on the
molecular level reaction demonstrated by the computer: “So it would be ZN solid plus CU 2 plus aqueous arrow ZN 2 plus, plus copper solid.” These examples demonstrate that the computer animation helped students visualize the molecular level of reaction and transfer a mental model of chemical reactions into a symbolic level of representations.

When there was confusion in solving the problems, the visual aids from microscopic animation seemed to help Group 3 clarify their uncertainty.

G3SA: [reads question] What is the oxidation half reaction that occurs? [points at the screen] Where does the oxidation reaction occur?

G3SB: Actually we can do ... wait ... the one is high in the activity series will be oxidized. So we can do is to which one is higher in the activity series.

G3SA: So the oxidation reaction happens on zinc?

G3SB: [points at the screen] Yeah ... oh wait ... it loses electrons and becomes ions.

Oh yeah I think it’s zinc.

G3SA: So zinc arrow ... ZN 2 plus, plus 2 electrons ... and ... anode?

Although group members were confused by this question, the microscopic level representation of the electron exchange made the equations on the activity series table explicit and helped students confirm their answer: “[points at the screen] Yeah ... oh wait ... it loses electrons and becomes ions. Oh yeah I think it’s zinc.” Apparently, the images and graphics demonstrated dynamically by computer animation made the ideas of chemical half reactions easier to understand than just the use of symbols and signs.

Activity 3 required students to conduct an electrolysis experiment by selecting the solution and metal strips for both electrodes in the computer simulation. The animations of electron movement and oxidation-reduction reactions took place after students clicked on the
power switch of the power supply. The direction of the electron movement was demonstrated explicitly by the computer simulation. Group 1 could easily identify the direction of the electron movement which was from the red wire (anode; “b” in the diagram of the worksheet) to the black wire (cathode; “a” in the diagram of the worksheet).

G1SA: I think it's red to black.
G1SB: Did you fill in the direction of electron flow?
G1SA: Of what . . .
G1SB: Red to black.

For the same task, the direction of the electron movement presented in the animation seemed to help student G2SA relate the symbols and signs in the half reaction equations to real life phenomena. She explained that the anode was oxidized and lost electrons and then used the computer simulation (pointed at the screen) to support her conclusion: “The anode is like . . . oxidized. So it lost electrons and became ions in the solution. So it’s B because electrons flow this way [points at the diagram]. So it’s A here.” The computer animation helped Group 2 members visualize the transfer of electrons between the electrodes and confirm their understanding of oxidation-reduction reactions:

G2SB: Well, [points at the screen] this one is losing electrons so it’s oxidized.
G2SA: So the nickel is oxidized. Iron is getting electrons here . . . so the iron in the solution get the electrons here then form iron solid.
G2SB: Yeah.

Similarly to the other groups, Group 3 also made use of the animation of electron movement to identify the electrodes (anode and cathode) for the electrolysis cell.

G3SA: What is the direction of the flow of electrons in the wire?
G3SB: [points at the screen]... red to black.
G3SA: [reads instructions]... which metal in the diagram is the anode?
G3SB: The cathode is the black wire... and the electrons are flowing from...
[points at the screen] red to black wire...
G3SA: So... [writes]...
G3SB: Half reaction at the anode...
G3SA: [writes]... NI 2 plus...
G3SB: Cathode gets electrons...
G3SA: Oh then it... [writes]...
G3SB: NI 2 plus... plus 2 E minus arrow... this is going to be NI...

For the three activities, the direction of the electron movement in the computer simulation helped students make a mental model of the electron exchange between oxidizing and reducing agents from the half reaction equations. The dynamic visual information in the computer animation seemed to make explicit the meaning of the relationship between symbols and numbers in the equation and help students accomplish the tasks. Electron transfer is a very important principle in electrochemistry. The computer animation of electron movement helped students visualize the process of electron exchange between electrodes and made explicit the definition of the anode and the cathode of an electrochemistry cell.

*Interference and Misunderstanding Caused by the Simulations*

Although the visual aid of the computer simulation was found to help students visualize the process of chemical reactions, some information provided by the computer simulations was found to confuse students and possibly increase the opportunities for misunderstanding.
In Activity 1, Group 1 and Group 3 did not show any confusion in ranking metals by their reactivity. However, the task and the computer simulation caused student G2SA to experience a dissonance in her understanding of the relationship between reactivity and standard reduction potential of the metals.

... they are more negative ... OK actually to what happened to the computer was flipping around ... is that we were starting with the solid Mg ... or no ... I think you are right, 'cause the ... [looks at the screen] ... OK if you flip it around, then you have made this change to solid ... [points at the attached activity series table].

The selection of metal strips for each new trial started with four metal strips that would react with metal ions in the solutions. Student G2SA was skeptical of such a scenario because the half reactions on the activity series table started from metal atoms in an ionic state and received electrons to become metal atoms.

In the second part of Activity 1, Group 2 members felt it was confusing when they placed the selected metal strips in the solutions that did not contain the ions of the selected metal strips for each electrode of the voltaic cell.

G2SA: Cu is forming from the solution on the zinc strip here ... [points at the beaker in simulation] ... so ... becomes metal ... and nothing happens to the zinc.

Isn’t ... there should be a reading on this ... Is there a reading on the meter?

G2SB: No.

Student G2SB placed a zinc strip into copper nitrate solution. No electron movement took place because electrons were transferred between the copper ion and zinc atom during the spontaneous reaction. No reading displayed on the monitor of the voltmeter because there was no electron movement. The result confused student G2SA.
G2SA: I think we are supposed to put the strips in their solutions.

G2SB: I think we are supposed point out the differences.

G2SA: I am going to get my book . . . . Yeah we are supposed to put the copper in the copper solution and the zinc in the zinc solution.

The simulation demonstrated results that conflicted with the students' prediction; and further, offered students the opportunity to reconsider their setup and hypothesis for the experiment without resetting all the apparatus.

In the same activity, Group 3 made a mistake by putting zinc metal in copper nitrate solution and vice versa. Therefore, the computer animation demonstrated that zinc atoms became zinc ions while copper ions became copper atoms and then the copper atoms deposited on zinc metal strip. Group 3 answered the question based on the animation and the attached standard reduction table. Without a correct setup for the voltaic cell, they still were able to answer the question without confusion because there was electron transfer between the oxidizing agent and the reducing agent when oxidation and reduction took place in the same solution. This case suggests that a redesign of the tutorial question may be necessary in order to direct students to correctly set up an electrochemistry cell. Student G3SA expressed her conclusion that this is not a spontaneous reaction because of her misinterpretation of the standard reduction potential of both metals: "But it's ZN 2 plus becomes ZN . . . so we should have positive point 76. Copper . . . positive point 34 . . . so I guess it's not spontaneous because both the standard reduction potentials are positive." However, they decided that this was a spontaneous reaction because "the reaction worked as soon as we put the metals and solution together." After a short discussion, they answered the question intuitively based on their observation of the computer animation.
The simulations were designed to match the real world situation of chemical reactions. Instead of helping students understand an electrochemistry cell, the molecular level of reactions that took place in simulation seemed to possibly cause Group 3 students to misunderstand the electrolysis cell. Group 3 students did not notice that there was no electron exchange between the two electrodes when the reaction between the metal strip and the ions took place in the solution of only one of the electrodes. Although Group 3 answered the question correctly, their conclusion “the reaction worked as soon as we put the metals and solution together” was actually based on their observation of the reaction that happened on only one of the electrodes. Group members did not seem to realize that the electron exchange between the two “electrodes” spontaneously was what the question asking. This example suggests a redesign of the computer simulation and the tutorial questions in order to draw students’ attention to the concepts and principles on which the whole learning activity was based.

In the same activity, when asked to judge if the reading of voltage from the computer simulation was a standardized cell potential, Group 3 seemed to hold misconceptions about the meanings of cell potential and standardized cell potential.

G3SA: . . . is this $E^{\circ}_{\text{cell}}$ or $E_{\text{cell}}$?

G3SB: Because . . . [looks at the equation on the blackboard] . . . oh no, we did just the EMF that is measured for the cell . . . Because we should plug in the equation with a lot of stuff.

G3SA: Because of what?

G3SB: Because we should plug into the equation and this is not what we get from the equation and is the measured EMF . . . .
G3SA: But E equals $E^o$ minus a lot of stuff... is it what we plug in? [looks at the equation on the blackboard].

G3SB: So it is going to be that so yours is not from the plug in equation... So it's going to be... $E_{cell}$.

G3SA: OK. [writes]... not from a table.

Students believed that the voltage read from the computer simulation was the standardized cell potential because it was the "measured" EMF. From their discussion, it appeared that they believed the $E_{cell}$ should be the calculated result from the equation rather than the reading (measured result) from the computer simulation: "Because we should plug into the equation and this is not what we get from the equation and is the measured EMF."

They did not seem to have the idea that the concentration of the solution played an important role in the definition of cell EMF. Their written answer for this question verifies their misconception: "This is the $E_{cell}$ because it's the measured EMF and not the standard EMF from a table." The activity and the information offered by the computer simulation revealed students' alternative conception of their understanding of cell potential. However, there were no further activities to lead students to recognize the mistakes they had made. Additional instruction and activities may be helpful in helping students build a conceptual understanding of this concept.

In an electrolysis reaction, the source metal is dissolved in an appropriate solvent, or melted, so that constituent ions are available in the solution. An electrical potential is applied across the electrodes immersed in the liquid. The cathode is negatively charged while the anode is positively charged. Each electrode attracts the ions of the opposite charge. Therefore, positively charged ions (cations) move towards the cathode while negatively charged ions
(anions) move to the anode. As a result, the source metal deposits on the cathode because the cations in the solution are the source metal atoms in ionic state.

In Activity 3, there were two tasks that students needed to accomplish. The first part asked students to construct an electrolysis cell using nickel metal for both electrodes. The second part required students to construct an electrolysis cell that caused iron metal to deposit on a nickel metal strip. In both tasks, students were asked to identify the anode and cathodes of the cell, to identify the direction of electron movement, to write down the half reactions of both electrodes, to identify the change of the mass of both electrodes during the reaction, and to judge if the reaction was a spontaneous reaction.

In this electrolysis simulation, the animation of electron movement stopped when the duration (selected by students) for the reaction expired. Ions in the solution moved randomly in the solution after the time for the reaction ended. This feature seemed to confuse Group 1 students:

G1SA: Direction of the flow... See the electrons didn’t flow either way... like no electron is going...[checks at the simulation but the time is up so no electrons are moving]

G1SB: Irons are just fooling around [in the solution].

G1SA: [writes] No electrons were flowing.

Student G1SA thought that there was no electron flow, while G1SB saw the iron ions just “fooling around.” They did not realize that the time for the reaction was up and the reaction had stopped. Given their confusion about the computer simulation, they still correctly answered the questions by referring to the computer animation of the reactions at
the electrodes. They stated that iron metal lost electrons and iron ions gained electrons on the nickel electrode:

G1SB: The anode is being oxidized . . . FE . . .

G1SA: How can electrons . . . iron [metal] lose electrons, you can tell iron loses electrons . . . So how are we going to say that?

G1SB: Because that one like . . . iron [ion] is taking electrons from here [nickel, black] . . . so it makes like both have electron exchange . . .

G1SA: OK . . . I don’t think they are going to buy it . . . but I don’t know what else I can do.

Although they had identified, correctly, that iron metal lost electrons while iron ions gained electrons on both electrodes, their answer for the half reaction at the cathode was: “\( \text{Ni}^{2+} + 2e^- \rightarrow \text{Ni} \),” which was not correct. The correct answer for this question should be: “\( \text{Fe}^{2+} + 2e^- \rightarrow \text{Fe} \).” It is likely that the students still held an alternative conception that depositing iron on nickel metal involved reactions of both metals. For Group 1, the animation seemed to work as a visual interference rather than an aid. In addition, Group 1 students tended to answer the last question with uncertainty because it was the end of the activity. The activity did not appear to provide sufficient opportunity for discussion and conceptual conflict, especially for the last question.

In the second task of this activity, Group 2 selected nickel for both electrodes and iron (II) nitrate as the solution in the bath. The following conversation shows what information the students received from the animation and their reaction toward the computer simulation.

G2SA: Oh . . . there is oxidation . . .
G2SB: Well [points at the red wire, anode], this one is losing electrons so it's oxidized.

G2SA: So the nickel is oxidized. Iron is getting electrons here . . . so the iron in the solution get the electrons here then form iron solid.

G2SB: Yeah.

The computer simulation was designed to replicate real laboratory situations. The reactions took place even with such an experimental setup because the power supply could drive the electrons from the anode through the circuit to the cathode with nickel metal oxidizing on the anode and iron ions (in the solution) reducing on the cathode. The animation showing that the iron ion was reduced on the nickel metal (cathode) made the students believe that they had correctly set up the equipment for the activity. The students did not notice that there needed to be a supply of the iron ions for the solution to keep the reaction going. In addition, student G2SA believed that this reaction was a spontaneous reaction because iron is more reactive than nickel.

G2SA: So nickel . . . I think iron will react with nickel . . . because I guess iron is more reactive than nickel . . . then iron in nickel solution would be more reactive than nickel in iron solution.

G2SB: Will nickel metal spontaneously react with iron (II) nitrate?

G2SA: Nickel metal . . . I think it will form ions in the solution. So I think it's a spontaneous reaction.

G2SB: Yeah. Why? Because . . . it will lose electrons? [writes] Ni will be oxidized and lose electrons . . . [writes]
Student G2SA failed to notice that although iron is higher on the activity series table than nickel, it is the iron in its atom state that will reduce the nickel ion in the solution. Group 2 made a mistake by selecting nickel metal for both electrodes; therefore, the difference of mass on the anode was $10.00 - 9.817 = 0.183$ while the difference of mass on the cathode was $10.174 - 10.00 = 0.174$. The anode was supposed to be connected with an iron strip as the electrode. When there is one iron ion generated and dissolved in the solution, one iron ion in the solution will become iron in a solid atom state on the cathode. As a result, the change of the mass of both electrodes should be the same. The animation showing the direction of electron movement helped students decide the gain/loss of electrons on each of the electrodes. However, the animation did not seem to successfully draw the students’ attention to the mistake they made on their configuration of the experiment. When nickel metal was selected as the anode, a nickel ion would be generated and dissolved in the solution while an iron ion would deposit on the cathode at the same time. The mass change on both electrodes therefore would be different due to the different atomic weight of the metal on the electrodes.

The molecular level of reactions that responded to Group 2’s incorrect setup seemed to have possibly contributed to their incorrect answers for the questions.

G2SB: [reads instructions] From your observation from the simulation, which metal in the diagram is the anode?

G2SA: ... lose electrons ... the anode is the red wire ... the anode loses electrons and oxidation occurs. So it’s B.

G2SB: Half-reaction at the anode ... nickel solid ... [writes] ... cathode ... Iron 2 plus, plus 2 E minus arrow iron solid ...

G2SA: OK, done.
Again, none of the students noticed that the anode was supposed to be iron for the electrolysis process. When compared to their written answers on the worksheet, we can find that they selected nickel metal for both electrodes but used iron (II) nitrate as the solution. Their answer for the half reaction at the anode, "Ni → Ni^{2+} + 2e^-", shows that they selected nickel for the anode. This finding indicates that restricting the selection of metals for the electrodes could possibly draw students' attention to the animation of the electrolysis process.

In the second task of Activity 3, Group 3 used the fact that in the simulation the power supply needed to be turned on to make the reaction happen as their criterion for non-spontaneity.

G3SA: [Setting up and run ...] ... this one is similar right? ... 10 minutes ... 
G3SB: Initial mass ... 10? ... iron ... uh ... one volt ... 
G3SA: Do you think this is spontaneous? 
G3SB: No I don't think so ... because we need to turn on the power supply to start the reaction. 
G3SA: [Writing] direction of electrons ... Red to black ...

Not many interactions occurred between Group 3 members. However, from their written answers for the worksheet questions, with the same configuration as they had in the first task (nickel-nickel electrodes), they made the same mistake that the other groups did by selecting nickel as the anode electrode.

An additional finding from students' activities was that all the groups missed the salt bridge in their drawn diagram of an electrochemical cell for the worksheet questions. When asked to draw a diagram for this electrochemical cell in Question 1e ("Draw a diagram for this electrochemical cell"), Groups 1 and 3 drew the diagram with the correct direction of
electron flow without difficulty. However, the salt bridge was missing in their diagrams. Although the salt bridge was statically demonstrated in both voltaic and electrolysis cell simulations, it is not surprising that the students drew the diagram without the salt bridge because the simulation and accompanying activities did not draw their attention to the function of the salt bridge. Group 2's diagram included the salt bridge, but the students drew electrons that flowed from zinc nitrate through the salt bridge to the copper nitrate solution. Such a misconception was commonly found in earlier studies (Sanger & Greenbowe, 1997a). Still, there was not enough information to show any conceptual conflict about this concept.

However, when answering Item “a” of Task 2 (Appendix A) in the final laboratory practical examination, G1SA and G2SA demonstrated their misconceptions about the salt bridge concept. This item asked student to draw lines showing the wire connection to the electrodes and voltmeter on a diagram and identify the names of the components to demonstrate the electrochemical cell that they constructed in the real life practical test. The salt bridge was printed as one of the components of the cell. Although students were not required to identify either the function or the name of the salt bridge, G1SA and G2SB drew symbols of electrons (e-) and arrows to show the movement of electrons in the salt bridge. Such a misconception is commonly found in students' understanding of electrochemistry (Sanger & Greenbowe, 1997a).

In order to reduce the students' cognitive workload for the task, the function of the salt bridge was not integrated into this computer simulation. As mentioned earlier, ignoring the concept of the salt bridge by statically demonstrating the salt bridge in the computer simulations may have contributed to this finding. Further investigations may be needed to see
if learning tasks regarding voltaic cell concepts without activities that focus on salt bridge principles help students build misconceptions about electrochemistry.

*Solving Problems with Simulations*

The activities for this study were designed based on an active learning strategy. Therefore, the tasks in the activities sought to promote interactions between group members and enhance students’ learning. The simulations used in this study have been found to promote discussion and interaction between group members. In addition, different groups seemed to solve problems in their own ways using computer simulations. Note that the problems here refer to the tasks and questions in the worksheets that students were asked to accomplish and answer. Examples of the above claims are organized in the following section.

*Promoting Discussions*

The tasks used in the study were designed based on an active learning strategy to help students learn electrochemistry. Collaboration is one component that helps students build their understanding because it promotes discussions between group members. In the second task of Activity 1, the simulation seemed to serve as the vehicle that promoted discussion between Group 2 members.

G2SB: So the anode would be ZN 2 plus?

G2SA: Um ... no ZN solid is reduced ... no ... oxidized, oxidized, and releases electrons. So this is the place that becomes 2 plus, 4 plus, 5 plus. So it should be Zn solid.

G2SB: Is this spontaneous? What do you think?
G2SA: Uh... it’s not, because the electron was going that way? [points to the screen]... No, what’s being reduced here? [Check answer]... copper is reduced. CU 2 plus... [points at the attached table]... it is spontaneous.

The movement of the electrons help G2SA confirm her conclusion for the task. She used the molecular level of animation to support the model she proposed for explaining why this reaction is a spontaneous reaction.

Confusion caused by the activity could possibly cause students’ dissonance and promote discussions. For example, in the first task of Activity 1, Group 1 and Group 3 did not show confusion about ranking metals by their reactivity. However, the task and the computer simulation caused student G2SA to experience a dissonance in her understanding of the relationship between reactivity and the standard reduction potential of the metals.

... they are more negative... OK actually to what happened to the computer was flipping around... is that we were starting with the solid MG... or no... I think you are right, ‘cause the...[looks at the screen]...OK if you flip it around, then you have made this change to solid... [points at the attached activity series table].

The selection of metal strips for each new trial started with four metal strips that would react with metal ions in the solutions. The animation demonstrated an oxidation reaction of the “metal” if students focused on the metal strip. Student G2SA was skeptical of such a scenario because the half reactions on the activity series table started from metal atoms in an ionic state and received electrons to become metal atoms, which are reduction reactions. The difference between the animation and attached activity series table caused G2SA’s dissonance. Her dissonance promoted discussions between group members when they were
asked to classify the pattern between the reactivity of metals and the attached standard reduction potential table (question 2d).

G2SB: No! Actually no... like I said, if you get 2 volts, that's all you need to have it to work, you know. Like I said, if you got it 2, that's it takes the volts [points at the activity series table] to do that.

G2SA: Ok now I am going to express myself, if I am wrong, I am wrong. If you flip these equations here, starting with like solid MG [points at the screen] and then you put it in... silver nitrate. So it becomes MG 2 plus, you know... nitrate...

G2SB: Yeah.

G2SA: ... and 2 electrons. That, this would be positive... [points at the activity series table]... right?

G2SB: I totally see what you were saying, but it's not exactly what I am thinking about... like... I don't think you could do that 'cause... 'cause these are E\(^0\) right?

Student G2SA argued that the more positive the standard reduction potential on the table, the more reactive the metal is because the simulation started from metals in solid state. Student G2SB was not confident with her own argument but was not satisfied with student G2SA's argument either.

G2SA: The high... the more positive E\(^0\), the more spontaneous, so if you flip it, then you switch the sign then more positive that E\(^0\) is, then it will be more reactive.

G2SB: You know... switch the sign don't turn out like... I am seeing what you are saying 'cause that's actually what I was trying. But I like to just try to see
where $H_2$ is ... $H_2$ kind of like standardizes it ... and they are going around like what you were doing. I don’t know why but it makes more sense to the question.

G2SA: If you read the book ... you do ... you end it up not ... you end up not putting $E^\circ$ in the point because the equations he [the researcher] gave us, you have the ... since the ... [points at the worksheet] ...

G2SB: They are the equations for reduction ...

G2SA: But they are both ... yeah ... ‘cause they are both ... like you are doing the reduction when it's the oxidation. But they don’t give you the oxidations so you have to flip it ... but then it like flips it back because the way the equation was originally causes it to make $E$ minus. So it's like you flip it and then you flip it back.

Student G2SB was confused by student G2SA’s argument. However, from her statement “But I like to just to try to see where $H_2$ (hydrogen) is ... $H_2$ kind of like standardize it ... and they are going around like what you were doing,” student G2SB had expressed that she realized the meaning of standard reduction potential, which is based on the relative tendency of the reduction of the hydrogen electrode. From the long discussion between G2SA and G2SB, it seems that the difference between the macroscopic level and the symbolic level of representations caused the dissonance between G2SA’s mental model of the oxidation-reduction reactions and promoted further discussion between group members.

In Activity 1, there was another example of discussion promoted by the activity. When asked if the voltaic cell is a spontaneous reaction, student G1SA expressed her confusion about the difference between the definition of free energy and the definition of cell potential.
“Yeah, ok I know that delta G is negative to make it spontaneous but on our quiz . . . I said that that one [reduction potential, points at the worksheet] was negative so it was spontaneous . . . .” G1SB pointed out GISA’s mistake and prompted a correction of GISA’s definition of free energy and cell potential.

G1SB: No, actually it’s positive!

GISA: Yeah, and I got it wrong. So this is . . . positive.

G1SB: Could we do it?

GISA: So when I wrote is negative in last night’s pop quiz . . . so this must have been that it is positive then it’s spontaneous.

G1SB: Yeah.

Student G1SA had difficulty identifying the change of free energy from cell potential before this activity because she pointed to the standard reduction potential table and concluded that the cell reaction is not spontaneous due to the negative potential. Student G1SB pointed out GISA’s mistake by pointing out the reading on the voltmeter of the computer simulation. The activity promoted communication between group members. Misinterpretation of electrochemistry principles was revealed during a conversation between group members; therefore, the conflict between the student’s existing understanding and the new information from the task help G1SA correct her understanding of the definition of the cell potential.

In Activity 2, the activity itself worked as a medium that recalled Group 2 students’ prior understanding about the tasks and further, promoted discussions between group members.

G2SB: OK . . . what am I measuring . . . E\text{cell} OK? [writing]
G2SA: OK when we did it, we didn’t decrease the molarity of zinc solution.

G2SB: What was the EMF of the cell? We were doing 1.11.

G2SA: Spontaneous . . .

G2SB: Why isn’t it $E^\circ_{\text{cell}}$?

G2SA: Because the molarities were no longer 1.0.

G2SB: Oh, OK.

G2SA: The "$\circ$" means standard, and for standard, the molarity needs to 1.0.

This example of students’ conversation showed that student G2SB’s confusion about the definition of standardized cell potential was reduced and her understanding became clearer by the explanation provided by student G2SA during their discussion. The activity seemed to promote discussion between group members and helped the students to recall their understanding of the principles of electrochemistry.

These examples indicate that the simulations could promote discussion between group members by causing dissonance that was generated by the differences between the visual information and students’ prior understanding. In addition, the activity itself was also found to help students recall their prior understanding during the discussion and possibly clarify students’ understanding of electrochemistry principles.

*Problem-solving Strategies with the Use of Simulations*

Before the simulations were available in the laboratory, when students were confused or needed assistance, they relied on the teaching assistant or notes written on the board as their primary source of help. The availability of the simulations provided an alternative source of help when students encountered difficulty with a task. Rather than the verbal explanation, the static symbols, or the drawing from the teaching assistant and notes on the
blackboard, the simulations provided dynamic visuals that represented the functions of
electrochemistry cells. In the first task of Activity 1, Group 1 members referred to the visual
aids as proof of evidence for their prediction of the answer to the question while they were
identifying the electrodes.

G1SB: The electrons are moving through the wire . . . .
G1SA: So CU. Because the atoms are all going around.
G1SB: No, the oxidation is actually done right here.
G1SA: Is that where it occurs? When we see these are all going to that one (copper
ions going toward the copper strip) and these are all going that way (zinc
atoms becoming zinc ions and move toward the solution) [points at the screen]
and that’s because electrons are all going here (copper strip).
G1SB: Yeah . . . But the ZN is losing electrons so that’s where oxidation occurs.
The molecular level computer simulation worked as support for G1SB’s argument in
their discussion. Group 1 had no difficulty answering questions such as identifying the
standard cell potential (E°). However, when writing down a chemical equation for the cell,
they appeared to rely on the equation written on the blackboard by the teaching assistant.
G1SB: So . . . [writes] . . . there is CU 2 plus aqueous plus . . . like . . .
G1SA: Yeh . . . plus . . .
G1SB: Plus Zn solid? And copper solid and ZN 2 plus . . . [checks the blackboard]
G1SA: Sounds ok . . .

When there were resources that were more accessible than the computer simulations,
the interaction with the computer simulations seemed to decrease. From the observation of
student interactions, there were instances when students looked for help from the notes on the
blackboard because the information on the blackboard could be accessed more directly than the information from the simulations. The following example shows that Group 3 relied on the formula on the blackboard for their predictions:

G3SA: ... is this $E^\circ_{\text{cell}}$ or $E_{\text{cell}}$?

G3SB: Because ... [looks at the equation on the blackboard] ... oh no, we did just the EMF that is measured for the cell ... Because we should plug in the equation with a lot of stuff.

G3SA: But $E$ equals $E^\circ$ minus a lot of stuff ... is it what we plug in? [looks at the equation on the blackboard].

Students used the simulation in a traditional laboratory class. The teaching assistant usually gave an introduction of the laboratory activity and provided some notes such as equations and formulas that were written on the blackboard at the beginning of the class. The formula and equations on the blackboard became one of the resources that could be used by the students to accomplish their tasks. Looking for answers from the blackboard might have possibly reduced the number of opportunities for students' discussion; and further, weakened the impact of the use of computer simulation on students' understanding. This example suggests a further study to investigate the impact of the use of computer simulations in an active learning environment.

Formulas and equations were the other sources that students used to accomplish tasks. In the tasks for Activity 2, students were asked to construct an electrochemistry cell to have a cell potential higher than 1.1V by changing the molarities of the solution in both electrodes. Group 1 used a formula to calculate the value of EMF before changing the molarities of the
solution on the simulation. They seemed to spend more time on getting the results from using
formula rather than from using the simulations.

G1SA: [goes back and gets her lab manual] in the equation . . . we have 2.0 for copper
when the ratio is smaller, then the lnQ is smaller . . . then what it said right
there?

G1SB: The smallest one is zero . . . so . . .

G1SA: Then . . . because you have . . . so that has to be smaller . . . so . . . yes . . . see
'tcause . . .

G1SB: Zn equals to .1 . . . and 2 (copper) [points at the question] .05 and then you
say . . .

G1SA: We are supposed to find the E cell, not this.

G1SB: I know! When this is smaller . . . then you minus less . . . and this is greater . . .
see!

As a result, students used the simulation and changed the molarities of the solutions to
generate the same reading as their prediction because there were constants in the formula that
they were not able to manipulate without a calculator. Group 1 was not the only group that
used the formula to generate the answer for this task. When asked to predict the cell potential
before constructing a voltaic cell, Group 2 students also depended on the formula for their
prediction.

G2SA: Yeah I can’t remember . . . I remember we got higher if we changed the
molarity in the formula.

G2SB: Actually one is molarity for the cathode; one is molarity for the anode.
The following conversation shows the progress of how students reached their prediction from the formula by using computer simulation.

G2SA: Yeah... so if we want it to be higher... we want it to...
G2SB: Lower the... lower the copper?
G2SA: Hm... I think... higher the solution... OK higher the copper... lower the zinc... OK, is why this increased? Because if we lower this... and then what?
[works on the simulation...]
G2SB: OK are we ready? Two molar [copper nitrate] and one molar [zinc nitrate]...
[watches]... one more time.
G2SB: [writes]... Increase the molarity of copper and decrease the molarity of zinc.
G2SA: Alright, we have 1.11 instead of 1.3.

After their discussion, they seemed to realize that the molarity of copper nitrate needed to be increased to generate a cell potential that was greater than 1.1 volts. The reading of the voltmeter in this computer simulation confirmed their prediction. Technically, for Group 1 and Group 2, the computer simulation, with its computational ability, seemed to work as a calculator that students could use to generate the reading to confirm their prediction.

For the same task, Group 3 used a different approach to accomplish the task. For example in Activity 2, when asked to construct a cell with a cell potential that would be higher than 1.1 volts, Group 3 simply guessed a number for their answer without giving an explanation on their worksheet.
G3SB: It has to be greater so we want... we want a higher copper and lower... zinc?

G3SA: I guess so... yeah... and...

G3SB: [points at screen]... higher...

G3SA:... higher concentration?... copper... right?

G3SB: Yeah...

G3SA:... OK... point one...

G3SB: Alright... you want to make this... lower (zinc)?

G3SA: Let's try the lowest (.001).

G3SB: We can do it in this way... more... here... and we lower this.

G3SA: You can put copper in copper, zinc to zinc as we did for the previous one but set the molarity next to them.

Unlike the other groups, Group 3 students made their prediction by guessing and then used the computer simulation to generate a reasonable reading to match their prediction. They reached their result by setting up different molarities for the solutions and looked for the values that were higher than 1.1 volts.

These examples indicate that students in different groups tended to use different strategies to solve problems for the tasks. Group 1 and 2 students made their predictions based on the relationship between the molarities of reducing and oxidizing agents in a formula. The simulation was used as a tool to confirm their prediction. Group 3 simply picked a number that was greater than the standardized cell potential as their prediction. They simply used the computer simulation in a trial-and-error manner just to generate a number to accomplish the task. Each group seemed to develop different approaches to solve problems
with the use of computer simulations. It would be helpful to realize how individual differences have an impact on students' learning with the use of computer simulations.

The Impact of Prior Knowledge

Students in this study were selected according their prior knowledge based on their ACS test scores. The purpose of grouping students is to realize how prior knowledge has an impact on their learning process and understanding. In this study, students' prior chemistry knowledge was found to have an impact on the interactions between group members, on the ways they used the computer simulations, and on how they accomplished the tasks. Examples of student interactions and conversations presented in the next section represent the findings regarding the research purpose.

Impact on Interaction with Group Members

In order to compare the degree of involvement of each group, the researcher observed students' interactions from the videotapes, and identified and recorded the duration of meaningful discussions between group members as "high involvement" seconds. The duration when students were expressing their understanding, raising questions about the results, and debating their predictions was recorded in units of seconds. These durations were added up and compared to the total seconds each group spent on each activity. The results are presented in Table 4.

Table 4.

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<th>Degree of Involvement</th>
<th>Number of seconds</th>
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<td>High Involvement</td>
<td>Activity 1</td>
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<td>Group 1 (High-High)</td>
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Table 4. (continued)

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<th></th>
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<td>Activity 1</td>
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<tr>
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<tr>
<td><strong>Group 3 (Low-Low)</strong></td>
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<tr>
<td><strong>Total</strong></td>
<td>601</td>
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</table>

In the first task of Activity 1, when asked to identify the pattern between metals’ reactivity and the standard reducing potentials on the activity series table, G2SA demonstrated her understanding of electrochemistry principles and dominated the discussion while working with the group member who had a lower ACS test score (G2SB).

G2SB: So the more reactive they are, the more positive they are?

G2SA: As we do it this way . . . it just like with . . . with this way is like you start with the . . . MG 2 plus like in the MG solution. What would it react with? Nothing. This liquid reacts with nothing because it’s so negative. You know the more negative it is, the less spontaneous it is.

G2SB: Why don’t we say they are reactive in the solution?

G2SA: Well it is MG 2 plus. MG 2 plus is liquid [pointing at the table].

G2SB: So . . . then . . . ?

G2SA: So it makes sense that they are liquid too.

G2SB: So . . . should I write something? The more reactive . . . the more reactive they are . . . the more positive or the more negative their reduction potential?
G2SA: This is the reductions, so if you say the more reactive then they are the more negative reduction potential they are.

G2SB: Yeah . . . [writes] the more reactive they are, the more negative their reduction potential is.

This pattern of interaction demonstrates the relationship between a group member’s level of prior knowledge and her or his response toward the task during group discussion. From the conversation between members in the group, the student with the higher prior knowledge level seemed to dominate the discussion when there was confusion about their conclusion. It is not surprising, because the student with the higher prior knowledge level was more confident with her answer and reasoning while the student with the lower prior knowledge level was less confident about her answers. As a result, the student with the lower level of prior knowledge seemed to be passively expecting the answer from G2SA: “So . . . should I write something? The more reactive . . . the more reactive they are . . . the more positive or the more negative their reduction potential?” G2SA explained her understanding of the concept to support her argument while G2SB received explanations from G2SA. This type of interaction, according to Webb, Troper, & Fall (1995), was helpful for G2SA to clarify or reorganize the information received in this activity and further fill in the gaps of her understanding. In addition, the student who received the explanations could also fill in the gaps in her understanding because she was given opportunities to correct her misconceptions and strengthen the connections between the new information and her prior understanding (Webb et al., 1995).
Compared to Group 2, there seemed to be less discussion between Group 3 students and that group accomplished the tasks with less questioning of or about their findings than the other groups.

G3SB: [reads instructions] Arrange the metals in order of increasing reactivity . . .

Well, Ag, Cu and Zn, and Mg.

G3SB: [reads instructions] Locate the magnesium, zinc, copper, and silver in the attached standard reduction potential table. Is there . . . [checks the attached table].


G3SB: Yeah, there’s a correlation, the more reactive, the more . . .

G3SA: The more negative.

G3SB: The more positive . . . the least reactive . . . on the table . . . [writes] . . .

This group’s work did not seem to lead to much interaction between students’ prior knowledge and the information provided by this activity. The two members tended to accept passively the results from the computer simulations and used the information to accomplish the worksheet tasks without experiencing conflict with their existing understanding. From the results in Table 4, Group 3 spent 198 of their total 601 seconds of activity time interacting while Group 2 spent 654 seconds of their total 957 seconds of activity time interacting. This result shows that Group 2 used a larger proportion (654/957) of their activity time than Group 3 did (198/601) discussing and communicating about issues regarding the tasks.

Impact on Solving Problems with Simulations

When tackling the problems for the tasks, high ACS score students’ prior knowledge seemed to work as the main resource for solving problems. In the second part of Activity 1,
students were asked to predict if the reaction in the voltaic cell was a spontaneous reaction. Group 1 reached conclusions based on their prior understanding of chemical reactivity. Their prior knowledge was revealed in their conversation:

G1SA: [reads question] Is it a spontaneous reaction? Explain . . .
G1SB: Spontaneous, its delta G is negative . . .
G1SA: I would say yes because it is not requiring any outside . . . like . . . help.

In this activity, there is a standard reduction potential table attached to the worksheet for students to compare the reactivity of different metals; however, students appeared to answer the question based on their prior understanding from the lecture instead of the information provided for this activity. In this example, student G1SB referred to delta G instead of the difference of the standard reduction potential of the metals as the reason for her judgment about whether a reaction was spontaneous or non-spontaneous. The responses to the questions also revealed students’ naïve conceptions about the principles of oxidation-reduction reactions. For instance, when asked to identify the anode and cathode of a zinc-copper cell, student G1SA explained her understanding of the electrodes of an electrochemistry cell: “I think it’s zinc and copper ‘cause they both get two positive so they can form atoms . . . .” She simply judged the electrode by recalling the half reaction equations without comparing the reactivity of different metals. G1SA still held her conception although her partner did not agree with her conclusion: “No . . . because one did not lose any electrons.” However, the activity did not provide sufficient opportunities for conceptual conflict with student G1SA’s understanding. As student G1SA stated: “And they’re both deposited . . . so . . . I don’t think so . . . I really don’t think so . . . but it doesn’t really matter.” Student G1SA appeared to ignore the hint on the definitions of oxidation, reduction,
anode, and cathode on the worksheet (Appendix C). In addition, student G1SA did not seem to be motivated to engage in further discussion, possibly because this activity had nothing to do with her grade and it was the last question they needed to answer.

Similarly to G1SA’s approach of solving problem, G2SA preferred using her prior chemistry understanding to solve the problem before trying the simulation. As in her conversation with her group member, “I like to make logic guess and watch it later,” the results provided by the computer simulations were used to confirm G2SA’s prediction that was generated by her mental model. In addition, when she needed to identify the anode of the voltaic cell, she described that the anode is the place where metal atoms switch from solid state to ion state: “So this is the place that becomes 2 plus, 4 plus, 5 plus. So it should be Zn solid.” The phrase, “2 plus, 4 plus, 5 plus,” represents the state of atoms that lose 2, 4, or 5 electrons during an oxidation reaction. Apparently, G2SA referred to the mental model of an oxidation reaction rather than the molecular level of animation provided by the computer simulations to support her argument. Therefore, it is not surprising that G2SA did not think the visual information provided by the computer simulations was helpful in accomplishing the tasks and made the following comment: “Yeah I don’t understand the volt meter at all... what is this doing to us... so this isn’t helping... ‘cause it doesn’t... like which one goes on red... doesn’t matter.”

Student G2SA (higher ACS score) stated the similarity between the computer simulation and the real laboratory activity: “If you break the computer, it doesn’t matter because we are doing exactly the same thing.” The same statement can also be found in student G1SA’s conversation: “I don’t know... it’s like what we do in the lab...” Thus,
these students, with higher prior knowledge of chemistry, seemed to be able to relate the scenarios in the computer simulations to their real world experience.

The computer simulations seemed to be more supportive to the group with low ACS scores than to the group with high ACS scores. Activity 2 required students to construct a voltaic cell and obtain a reading of cell potential that was greater than 1.10. Students were asked to predict the value of their setup before they turned on the power supply for the experiment. As in the examples in the previous section of this paper, the activity helped Group 1 and 2 recall their understanding of the formula for their prediction. Group 3 simply guessed a value that was greater than 1.10 to fill in the blank on the worksheet without giving any explanation for their prediction. As a result, they spent time working on the simulation rather than on the formula for their prediction.

G3SA: It has to be greater than 1.1 . . . [works on simulation]
G3SB: It has to be greater so we want . . . do we want to try a higher copper and lower . . . zinc?
G3SA: I guess so . . . yeah . . . and . . . [works on simulation]
G3SB: [Points at copper (II) nitrate solution] . . . higher . . .
G3SA: . . . higher concentration? . . . copper . . . right?
G3SB: Yeah . . .
G3SA: [Works on simulation] . . . OK . . . point one . . .
G3SB: Alright . . . you want to make this (zinc) . . . lower?
G3SA: Let's try the lowest (.001).

Group 3 was composed of two students who had ACS scores that were 10 points lower than the average score. Whereas the high ACS score group (Group 1) and the mixed
group (Group 2) recalled their understanding of the formula to predict the result for this task, Group 3 relied mainly on the simulations for their prediction.

The examples mentioned in this section indicate that, in this study, the computer simulations seemed to work differently for students with different levels of prior chemistry knowledge. Students with a high level of prior chemistry understanding tended to depend mainly on their prior knowledge to predict and plan for accomplishing the tasks. The computer simulations worked as tools to confirm their predictions and conclusions. For the students with a low level of prior knowledge, the computer simulation worked as a major resource that they could use to generate answers for accomplishing the tasks after several trials. However, the results showed that simply trying different setups on the simulation to get answers did not seem to promote meaningful discussion for learning activities.

For the more open-ended questions such as the question in this activity, Group 3 seemed to need more guidance about the activity than the other groups did to have a deeper conceptual understanding of the meaning behind the computer simulations. This finding confirms Rieber's (1989) conclusion that students with lower ability need more guidance on computer simulation integrated learning activities to help them achieve a learning outcome.

Discussion

Students with different prior chemistry knowledge levels reacted differently during their discussion and toward the computer simulations. Fewer interactions between group members were revealed in the group that was composed of students with a lower level of prior knowledge (Group 3) than in the groups that were composed of at least one student who had a higher prior knowledge level. When working with the computer simulations, the high ACS score group and the mixed group were more likely to refer to their prior understanding
to predict their findings and come to conclusions for the tasks than the low ACS score group did. This study found that students with high ACS scores seemed to provide more verbal explanations about their predictions and arguments when working on the simulation than did low ACS score students. It was likely that high ACS score students had fewer difficulties relating the visual information to the equations, formulas, and their mental models for the answers than the low ACS score students. This finding confirms Kozma and Rossell's (1997) conclusion that students with a higher level chemistry background seem to be more capable of transforming different formats of representations into chemistry statements than those who have a lower level chemistry background.

Kozma and Rossell (1997) found that when dealing with information in different representations, novices tended to gather all the information they could get together whereas experts analyzed and organized information more precisely and accurately. According to the findings of this study, students with more chemistry knowledge might already have constructed more solid mental models for explaining chemistry phenomena. Therefore, they could more easily predict the results and make conclusions from the symbols and signs in the equations for the problems. Without sufficient chemistry background, information from the computer simulations served as the main resource for students with low level prior knowledge to complete the tasks. In this study, students with high-level prior knowledge seemed to plan and make prediction on the tasks before trying the computer simulations for their answers. Students with low-level prior knowledge worked on the simulations in a trial-and-error manner. Such instances demonstrate that students used different strategies to solve problems while using computer simulations to learn chemistry. Although it is not age-related, the knowledge level related problem solving approaches students used seems to
share the same with Piaget's (1964) “stages of cognitive development” argument. In terms of
problem solving, students with high level prior chemistry understanding seemed to be able to
perform “hypothetical thinking” when asked to accomplish the tasks using computer
simulations. In this study, the questions in the worksheets were designed based on an active
learning strategy. Therefore, the tasks required students to explore electrochemistry principles
with limited guidance. However, students with insufficient prior chemistry knowledge did not
seem to investigate a problem in a careful and systematic fashion like those who had
adequate prior knowledge of chemistry concepts. The context of the activities with the use of
computer simulations did not seem to provide situations that were concrete enough for those
who had insufficient prior chemistry knowledge to solve problems. As a result, students with
high level prior knowledge in this study can likely be related to children in the “formal
operations” stage while students with low level prior knowledge can be related to children in
the “concrete operations” stage when being compared to Piaget’s (1964) stages of cognitive
development theory.

The activities were designed based on an active learning strategy and they seemed to
promote more discussions in the groups with higher prior knowledge level students than in
the group with lower prior knowledge level students. As discussed above, high ACS score
students were more able to relate the visual information to their prior understanding and to
provide more verbal explanations and predictions. Therefore, the group comprised of two low
ACS score students seemed to accomplish their learning activity without any explanation
provider (Webb et al., 1995). As a result, it is not surprising that fewer interactions occurred
in the low ACS score group.
The molecular level animations of chemical reactions and electron movement were found to have helped students accomplish the tasks. Students frequently referred to the animations that demonstrated the movement of electrons as support for their reasoning. It is likely that the direction of the electron movement in the animation made the symbols and signs in the oxidation-reduction chemical half reactions explicit to students. The visual information seemed to help students connect the meaning of the equations with the molecular level animations and help them build mental models of the reactions. For the high ACS score students, the equipment in the simulations did not seem to make too much sense to them. For example, student G2SA (high level) stated: “Yeah I don’t understand the volt meter at all . . . what is this doing to us . . . so this isn’t helping . . . ‘cause it doesn’t . . . like which one goes on red . . . doesn’t matter.” The voltmeter in the simulation did not make sense to her because it was very likely that she could easily identify the cathode and anode based on the movement of the electrons in the simulation based on her understanding of oxidation and reduction reactions. This example agreed with Rieber's (1989) findings that students with a higher level background knowledge seemed to need just to be prompted to pay attention to the related details.

In addition, students were found to make use of the computational ability of the computer simulations to prove their predictions. High ACS score students had more discussions about the formula and equations before using the simulations to prove their prediction than low ACS score students had. Students with a lower prior knowledge level seemed to use the output from the computer simulation with fewer discussion and questions about the results. More guidance on the process of the activities might be useful to promote involvement on the tasks, especially for lower prior knowledge level students. In addition, the
open-ended style design of the computer simulation might not be helpful to students with insufficient chemistry background (ChanLin, 2001). This finding suggests the consideration of an alternative style of design, for example, a linear style of simulation that could possibly reduce the cognitive workload of students with insufficient prior knowledge (Rieber, 1994).

For Activity 3, the Electrolysis cell, none of the students wrote the half reaction equation for the anode correctly. Their mistakes reflected their selection of nickel metal rather than iron metal as the electrode. This task required group members to select electrodes for depositing iron metal on a nickel metal electrode. None of the students noticed that it required the iron metal as the anode to release iron ions and maintain the concentration of the ions in the solution for the reaction to keep proceeding. This part of simulation reflected the real world situation that the reaction took place even when students did not select iron as the anode because there were already iron ions in the solution when the power supply was turned on. The power supply in the solution would drive the electrons from the anode to the cathode and force the oxidation-reduction reaction to take place when there were anions and cations in the solution. In reality, the reduction of iron ions stops and the electrolysis process of water molecules takes place when there is no supplement of iron ions in the solution. The simulation demonstrated the process with simplified animation in order to reduce the complexity of design and to reduce students' cognitive workload. However, students were not aware of the difference because the reduction reaction took place when there was a response from the computer to their configuration of the experiment. No interaction shows whether such a design promoted students' alternative conceptions of the concept of electrolysis. In this study, identifying the anode in an electrolysis process seemed to be the hardest topic to students. Students tended to set up the experiment based on their interpretation of a voltaic
cell. However, the ion flow in the same bath rather than in two separated beakers seemed also to confuse students with regard to answering worksheet questions. Therefore, this finding suggests the need for further studies on the design of simulations to understand whether certain designs promote students' misconceptions. In terms of the design of the computer simulations, restriction of students' selection of electrodes may be useful in helping them focus on the target concept because they work on the computer simulation for only a limited length of time. In addition, it would be beneficial for students if the animation of the reaction would stop when there is not a sufficient supply of iron ions for the solution.

The Design of the Activities

Obviously, it was the activities, the integration of the tasks, and the use of computer simulation, rather than computer simulations alone, that promoted interactions between group members. In the present study, computer simulations were commonly used as tools to provide information that motivated students to discuss, predict, and analyze their answers for the assigned tasks. Based on an active learning strategy, the activities were designed in an open-ended fashion to encourage students to engage in discussions and therefore achieve conceptual changes about chemical principles and concepts. However, the volunteer participants needed to accomplish the real life lab tasks as well as the computer simulation activities in a 3-hour laboratory section. Due to the time constraint, students may not have had adequate time and opportunity to have a deep involvement in the activities. Furthermore, the laboratory section was designed in a “cook book” style, which is contradictory to an active learning strategy. The findings show that the students were likely to seek help from the notes and instructions written on the blackboard by the teaching assistants or from their textbook and notes taken from lecture as their main resources for completing the tasks.
Therefore, students did not seem to be placed in a fully active learning environment due to the gap between the actual lab and the simulation activities. It would be helpful to understand how the use of computer simulation in an active learning setup affects students' understanding if they were to have sufficient time to work on the activities with the use of the computer simulations.

Conclusions

This study investigated how students' prior understanding has an impact on their interactions with computer simulations and on their interactions with group members through the use of computer simulations that were designed to help students learn electrochemistry. The visual information provided by the computer simulations, especially the molecular animations, helped students connect their understanding of chemical reactions to the chemical equations that present chemical reactions with representations such as symbols and signs. Meanwhile, students with different levels of prior knowledge used the computer simulations differently for solving problems. The computer also promoted students' interactions with the computer and with group members. However, more interactions were demonstrated between students with a higher level of prior knowledge than between students with a lower level of prior knowledge. Computer simulation itself did not seem to fit the needs of all the students in the present study. Considerations of individual differences, the integration of learning materials, and teaching/learning strategies on the design of a learning system would be essential components in helping students build their understanding of electrochemistry.

References


CHAPTER 5. GENERAL CONCLUSIONS

As the popularity of computer simulations that help students understand chemistry is increasing in today’s classrooms, it is important to realize how the instructional use of computer simulations affects students’ understanding of chemistry principles. Computer simulations can produce representations of molecular events that improve student’s understanding of particular matter and mechanisms of chemical reactions. Chapter 2 presented a review of the literature from research that studied the impact of the use of computer simulations in helping students learn science. Chapter 3 in this dissertation revealed the impact of the use of a series of computer simulations on students’ understanding of electrochemistry principles. In addition, the interactions between students’ prior knowledge and the use of computer simulations were documented. Chapter 3 also presented the results of the investigation of the influence of an individual’s motivation and learning strategies on her/his understanding and learning with the use of computer simulations. Chapter 4 provided insights into how the use of computer simulations affects the communication between group members and how individuals with different levels of prior knowledge respond to computer programs and interact with peers. Key findings from this dissertation and recommendations for further research are discussed in the following sections.

**Key Findings from the Dissertation**

Chapter 2 provided a review of the literature that documents the impact of the use of computer simulations on students’ learning, especially in learning science. From the studies reviewed in Chapter 2, learners were found to comprehend the meaning of natural phenomena and science theories better with descriptions and explanations of the science principles in both verbal and visual formats than in verbal format alone. With the capability
of generating dynamic visuals to represent the molecular level of natural events, the use of computer simulations have been found to have a positive impact on students’ understanding of the mechanism of chemical reactions. However, an individual’s prior knowledge and learning strategies have also been found to have an impact on her/his response to computer simulations and therefore affect the potential value of computer simulations. The results in Chapter 3 showed that there is no significant difference on students' performance between students who use the computer simulations and those who use traditional approaches in learning electrochemistry. Research design issues such as the sample size, the reliability of the test items, and the integration of the laboratory and simulation activities might have affected the value of the results. The findings agreed with findings in earlier studies that college students seem to have the ability to build mental models from the text and symbols of scientific models with or without the help of computer simulations. The results also showed no significant correlations between students’ learning strategies and learning outcome with the use of computer simulations. The questionnaires used to detect students’ motivation and learning strategies were developed based on traditional learning activities and may not fit the learning activities of this study because of the limited time for using the computer simulations. Although students’ prior knowledge levels were found to have a significant correlation with students’ performance, no interactions were found between the use of computer simulations and student’s prior knowledge. These findings show that it was students’ prior knowledge that played a key role in affecting their understanding of electrochemistry. The study in Chapter 3 indicated that it is likely that the design of the learning activities rather than the use of technology actually has an impact on students learning.
Chapter 4 presented an in-depth study of students' use of computer simulations in learning electrochemistry. Although in Chapter 3 there were no significant impacts of the use of computer simulations on students' learning, Chapter 4 documented cases that show how computer simulations affect students' interactions with peers and with the computer. In this study, students tended to make use of the animations that demonstrate the molecular level of chemical reactions to support and prove their predictions and arguments with peers. This study also found the computer simulations promoted interactions between group members. Meanwhile, students with different prior knowledge levels were found to use different approaches to solving problems. In particular, the cases showed that some students with a high level of prior knowledge expressed that the simulations did not make more sense than the real life laboratory setups; and further, they tended to use the equations and formula to accomplish the tasks and then use the computer simulations to confirm their predictions. The students with insufficient prior chemistry knowledge did not seem to be able to efficiently make predictions of the outcomes using formulas and equations. Therefore, the computer simulations worked as the main resources for them to accomplish their tasks. In this study, although prior knowledge was not found to interact with the use of computer simulations in affecting students' understanding, the findings in Chapter 4 show that in this study, prior knowledge seems to affect the ways that students solve problems and the ways they interact with the computer simulations.

**Suggestions for Further Research**

This study examined the impact of the use of computer simulations on students' understanding of electrochemistry. However, in terms of research design, the sample size of this study did not seem to be large enough to have sufficient power to predict the results.
Further studies with adequate sample size would be helpful to examine the influences of the use of computer simulations. In this study, students in the treatment group needed to accomplish the computer simulation tasks as well as the real-life laboratory tasks resulting in a time constraint of students’ real-life laboratory activities. The high cognitive workload and the limited time for computer simulation experience might have hindered students from deep thinking. It would be helpful to study if replacing the traditional “cook book” style laboratory with computer simulations in an active learning setup could have an impact on students’ understanding. Further research is needed to investigate how an active learning environment in which students are allowed to fully engage in the computer-assisted activities helps students learn science.

The overall quantitative study did not show significant interactions between the use of computer simulations and student’s prior knowledge. From the findings in Chapter 4, prior knowledge seems to have an effect on how an individual proceeds through tasks. The findings suggested an ongoing investigation on how students use computer simulations to learn science since individual differences seem to play an important role in the instructional use of computer simulations. Studies would be needed to investigate if providing different formats of support with the simulations could help students with different prior knowledge levels understand science concepts and theories.

While integrating the emerging new technology that can potentially help students in learning, considerable continuing research needs to be done because there are always issues that need to be identified and resolved when individual differences are considered. Meanwhile, it is important that the design of learning activities be given a higher level of
priority than the use of instructional technology when employing computer simulations in the classroom.
APPENDIX A. ELECTROCHEMISTRY TEST ITEMS IN FINAL COMPREHENSIVE EXAM

(5) An electrochemical cell has silver metal in 1 M silver nitrate and nickel metal in 1 M nickel(II) nitrate. Electrons in the cell flow from the _____ toward the _____.
   a) wire, silver electrode   c) salt bridge, nickel electrode
   b) wire, nickel electrode   d) salt bridge, silver electrode

Part III. Multiple Choice (3 pts each/total 30 pts)

(21) A solution of PtBr₃ is electrolysed using two platinum electrodes. Assuming no gas evolution at the cathode, for how many seconds must a current of 1.93 A flow to deposit 1.95 g of Pt metal?
   a) 35623 s   b) 2000 s   c) 500 s   d) 1000 s

(22) An aqueous solution containing 1.0 M NaNO₃ and 1.0 M HCl is electrolysed with inert electrodes. Using the \( E^\text{oc} \) values listed on the information sheet, what is the half reaction that occurs at the cathode during the electrolysis?
   a) \( \text{Na}^+(aq) + e^- \rightarrow \text{Na}(s) \)
   b) \( 2\text{H}_2\text{O}(l) + 2e^- \rightarrow \text{H}_2(g) + 2\text{OH}^-(aq) \)
   c) \( \text{NO}_3^-(aq) + 4\text{H}^+(aq) + 3e^- \rightarrow \text{NO}(g) + 2\text{H}_2\text{O}(l) \)
   d) \( 2\text{H}^+(aq) + 2e^- \rightarrow \text{H}_2(g) \)

(23) Given a cell based on the spontaneous reaction: \( 2\text{AgCl}(s) + \text{Zn}(s) \rightarrow 2\text{Ag}(s) + 2\text{Cl}^- + \text{Zn}^2+ \)
If the Zinc ion concentration is kept constant at 1 M and the chloride ion concentration is decreased from 1 M to 0.001 M, the expected change in cell voltage is
   a) increase by 0.06 V   d) decrease by 0.18 V
   b) increase by 0.18 V   e) increase by 0.35 V
   c) decrease by 0.06 V

(24) Use the following standard reduction potentials in V:
   \( \text{Ag}^+ \rightarrow \text{Ag}, +0.80; \text{Fe}^{3+} \rightarrow \text{Fe}, -0.41; \text{Fe}^{2+} \rightarrow \text{Fe}, -0.04; \)
   \( \text{Mn}^{2+} \rightarrow \text{Mn}, -1.18; \text{Zn}^{2+} \rightarrow \text{Zn}, -0.76 \).
   The electrical potential of the cell represented above is 0.46 ± 0.01 volts. Identify X.
   a) Ag   b) Fe   c) Mn   d) Zn

(25) Which of the following reagents is capable of transforming \( \text{Cu}^+(aq) \) to \( \text{Cu}(s) \) under standard-state conditions?
   a) \( \text{I}^-(aq) \)   b) \( \text{Ni}(s) \)   c) \( \text{Al}^{3+}(aq) \)   d) \( \text{F}^-(aq) \)

(26) Given the following standard reduction potentials.
   \( \text{Ag}^+(aq) + e^- \rightarrow \text{Ag}(s) \) \( E_e^0 = 0.80 \text{V} \)
   \( \text{AgCN}(s) + e^- \rightarrow \text{Ag}(s) + \text{CN}^-(aq) \) \( E_e^0 = -0.01 \text{V} \)
   What is the solubility product constant \( K_{sp} \) of AgCN at 25 °C?
   a) \( 4.3 	imes 10^{-14} \)   b) \( 2.3 	imes 10^{-14} \)   c) \( 2.0 	imes 10^{-14} \)   d) \( 5.1 	imes 10^{-13} \)   e) None of these

(27) The following reaction: \( \text{Zn}(s) + 2\text{H}^+(aq) \rightarrow \text{Zn}^{2+}(aq) + \text{H}_2(g) \)
What is the \( \Delta G^\circ \) of this reaction?
   a) 146.68 kJ/mol   b) -146.68 kJ/mol   c) 73.34 kJ/mol   d) -73.34 kJ/mol

(28) In the following reduction-oxidation reaction:
   \( 5\text{Fe}^{2+}(aq) + \text{MnO}_4^-(aq) + 8\text{H}^+(aq) \rightarrow 5\text{Fe}^{3+}(aq) + 4\text{H}_2\text{O}(l) + \text{Mn}^{2+}(aq) \)
What is the element being reduced when the reaction takes place?
   a) iron   b) oxygen   c) hydrogen   d) manganese
APPENDIX B. ELECTROCHEMISTRY TEST ITEMS IN LABORATORY PRACTICAL EXAM
APPENDIX C. EXAMPLE OF CHECKLIST OF STUDENT LABORATORY REPORT GRADING FORM FOR OXIDATION-REDUCTION AND ELECTROCHEMISTRY

Cut out this form and staple it to your report.

<table>
<thead>
<tr>
<th></th>
<th>No (0)</th>
<th>Yes (1)</th>
<th>Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Title</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Purpose</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Outline of procedure</td>
<td>None (0)</td>
<td>Major omissions (1)</td>
<td>Minor Omissions (2)</td>
</tr>
<tr>
<td>Data/Observation</td>
<td>None (0)</td>
<td>Major omissions (1)</td>
<td>Minor Omissions (2)</td>
</tr>
<tr>
<td>Balanced equations</td>
<td>None (0)</td>
<td>Major omissions (1)</td>
<td>Minor Omissions (2)</td>
</tr>
<tr>
<td>Calculation</td>
<td>None (0)</td>
<td>Major omissions (1)</td>
<td>Minor Omissions (2)</td>
</tr>
<tr>
<td>Graphs</td>
<td>None (0)</td>
<td>Major omissions (1)</td>
<td>Minor Omissions (2)</td>
</tr>
<tr>
<td>Quality of results</td>
<td>None (0)</td>
<td>Major omissions (1)</td>
<td>Minor Omissions (2)</td>
</tr>
<tr>
<td>Discussion</td>
<td>None (0)</td>
<td>Major omissions (1)</td>
<td>Minor Omissions (2)</td>
</tr>
</tbody>
</table>

**TA Evaluation**

<table>
<thead>
<tr>
<th>The student was adequately prepared to perform the experiment.</th>
<th>No (0)</th>
<th>Yes (1)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall, the student demonstrates a reasonable understanding of the experiment by doing the work with minimum confusion, by the analysis of the data, and by the discussion of the results.</td>
<td>No (0)</td>
<td>Yes (1)</td>
<td></td>
</tr>
</tbody>
</table>

Total points (25 maximum) |     |     |     |
APPENDIX D. TUTORIALS

1. Electrochemistry Simulation

Section ______
Name ________________________ Partner's Name ________________________
Today's date: ___________ Time (now) ______________

Instructions: You and your partner will be working with a computer simulation that covers electrochemistry, please discuss each question with your partner and write down your best answer.

Section 1. Activity Series (Type in the names of both group members in the login window.)

Activity 1
1) Pick one of the four metals and follow the instructions on the screen. Please write down your observations (e.g. what reactions occurred). Repeat this procedure for the other three metals and make sure to write all your observations down.
Your brief observations (PLEASE PRINT):

2) Considering magnesium, zinc, copper, and silver
a) Which of the four metals you tested is the most reactive? Briefly explain why (PLEASE PRINT).

b) Which is the least reactive? Why? (PLEASE PRINT)

c) Arrange the metals in order of increasing reactivity (from least reactive to most reactive)

d) Locate the magnesium, zinc, copper, and silver in the attached standard reduction potential table. Is there a correlation between the reactivity of metals and the table? Explain why or why not. (PLEASE PRINT)

Click on the “Activity 2” button when you are done with Activity 1.
Section 2. Electrochemical cells

Activity 2
1. Begin by assembling a zinc-copper cell. Please be sure to follow the instructions on the screen.
2. Is there an electron transfer between species? If so, complete the following table:
(PLEASE PRINT)

<table>
<thead>
<tr>
<th></th>
<th>Zinc</th>
<th>Copper</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mark the species that loses electrons</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Write down the appropriate oxidation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>half reaction under the species that is</td>
<td></td>
<td></td>
</tr>
<tr>
<td>undergoing oxidation.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mark the species that gains electrons</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Write down the appropriate reduction</td>
<td></td>
<td></td>
</tr>
<tr>
<td>half reaction under the species that is</td>
<td></td>
<td></td>
</tr>
<tr>
<td>undergoing reduction.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The anode half cell is: (circle one</td>
<td>a. Zn$^{2+}$ b. Zn c. Cu$^{2+}$ d. Cu</td>
<td></td>
</tr>
<tr>
<td>answer)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The cathode half cell is: (circle one</td>
<td>a. Zn$^{2+}$ b. Zn c. Cu$^{2+}$ d. Cu</td>
<td></td>
</tr>
<tr>
<td>answer)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

As a reminder:
Oxidation: A process in which a substance loses one or more electrons
Reduction: A process in which a substance gains one or more electrons
Anode: an electrode at which oxidation occurs
Cathode: an electrode at which reduction occurs

3. Is this a spontaneous reaction? Explain your reasoning. (PLEASE PRINT)

4. Write the complete balanced equation for the reaction. (PLEASE PRINT)

Click “Click here when you are done!” button when you are done.
### Standard reduction potential table

<table>
<thead>
<tr>
<th>Reaction</th>
<th>Standard Potential (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\text{Li}^+ + e^- = \text{Li}$</td>
<td>-3.04</td>
</tr>
<tr>
<td>$\text{Na}^+ + e^- = \text{Na}$</td>
<td>-2.71</td>
</tr>
<tr>
<td>$\text{Mg}^{2+} + 2e^- = \text{Mg}$</td>
<td>-2.38</td>
</tr>
<tr>
<td>$\text{Al}^{3+} + 3e^- = \text{Al}$</td>
<td>-1.66</td>
</tr>
<tr>
<td>$2\text{H}_2\text{O(l)} + 2e^- = \text{H}_2 + 2\text{OH}^-$</td>
<td>-0.83</td>
</tr>
<tr>
<td>$\text{Zn}^{2+} + 2e^- = \text{Zn}$</td>
<td>-0.76</td>
</tr>
<tr>
<td>$\text{Fe}^{2+} + 2e^- = \text{Fe}$</td>
<td>-0.41</td>
</tr>
<tr>
<td>$\text{Ni}^{2+} + 2e^- = \text{Ni}$</td>
<td>-0.23</td>
</tr>
<tr>
<td>$\text{Sn}^{2+} + 2e^- = \text{Sn}$</td>
<td>-0.14</td>
</tr>
<tr>
<td>$\text{Pb}^{2+} + 2e^- = \text{Pb}$</td>
<td>-0.13</td>
</tr>
<tr>
<td>$\text{Fe}^{3+} + 3e^- = \text{Fe}$</td>
<td>-0.04</td>
</tr>
<tr>
<td>$2\text{H}^+ + e^- = \text{H}_2$</td>
<td>-0.00</td>
</tr>
<tr>
<td>$\text{Sn}^{4+} + 2e^- = \text{Sn}^{2+}$</td>
<td>+0.15</td>
</tr>
<tr>
<td>$\text{Cu}^{2+} + 2e^- = \text{Cu}$</td>
<td>+0.34</td>
</tr>
<tr>
<td>$\text{Fe}^{3+} + e^- = \text{Fe}^{2+}$</td>
<td>+0.77</td>
</tr>
<tr>
<td>$\text{Ag}^+ + e^- = \text{Ag}$</td>
<td>+0.80</td>
</tr>
<tr>
<td>$\text{Hg}^{2+} + 2e^- = \text{Hg}$</td>
<td>+0.85</td>
</tr>
</tbody>
</table>
2. Electrochemistry Simulations: Voltaic Cell EMF

Section __________
Name ____________________________  Partner's Name ____________________________
Today's date: ____________  Time (now) ________________

Please mark one of the following:
Your actual lab regarding Voltaic Cell EMF is: Finished ____  Not done yet ____

1. Start the software and construct a zinc-copper electrochemical cell using 1.0 M Zn\(^{2+}\) and
1.0 M Cu\(^{2+}\) solutions.

   a. What is the EMF of this cell (include units)? _________________

   b. For the voltage that you are measuring, is this \(E^\circ_{\text{cell}}\) or \(E_{\text{cell}}\)? ____.
      Please explain (PLEASE PRINT).

   c. Write the chemical equation that represents the reaction occurring in this cell.

   d. Is this a spontaneous or non-spontaneous reaction? _________________.
      Please explain (PLEASE PRINT).

   e. Draw a cell diagram for this electrochemical cell.

   f. What is the oxidation half-reaction that occurs? _________________

      Where does it occur? (At which electrode?) _________________
      (Look at the molecular level animation.).

      The anode is ________.

2. Construct an electrochemical cell for which the EMF of the cell is greater than +1.10 V.
Before doing the simulation, predict the EMF of the cell.  Your prediction: ________
please explain (PLEASE PRINT). (The \(E^\circ\)s of metal will show when you move your mouse
to the bottom-right corner of this movie.)
a. Draw the cell diagram of the electrochemical cell that you construct.

b. What is the EMF of this cell (include units)?___________

c. Is the voltage that you are measuring $E^\circ_{\text{cell}}$ or $E_{\text{cell}}$? _________________

d. Is this a spontaneous or non-spontaneous reaction? _______________________

e. What is the oxidation half-reaction that occurs? _______________________

Where does it occur? (At which electrode?) _________________

(Look at the molecular level animation.)

The anode is __________.

f. Write the chemical equilibrium equation that represents the reaction occurring in this cell.

Click “Click here when you are done” button when you are done with the tasks.

3. Electrochemistry Simulations: Electrolysis

Section __________
Name __________________ Partner’s Name _______________________
Today’s date: ___________ Time (now) ______________

Please mark one of the following:
Your actual lab regarding Voltaic Cell EMF is: Finished _____ Not done yet _____

1. Set-up the electrolysis experiment and connect two strips of nickel metal to a power supply and select nickel (II) nitrate as the solution.
2. Select the mass of each electrode by dragging the slider and record the initial mass of each electrode.
3. Set the voltage and the current on the power supply. Select the amount of time you want the current to flow.

   a. Before you begin the simulation, make the following prediction:

   Will **nickel metal spontaneously react** with aqueous nickel (II) nitrate?
   Yes ______ No ______

   b. Turn on the power supply. Observe what happens in the bath. At the end of the experiment, record the initial and final mass of each electrode in the table below.

<table>
<thead>
<tr>
<th>Nickel on the red wire</th>
<th>Nickel on the black wire</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial mass</td>
<td>Final mass</td>
</tr>
<tr>
<td>g</td>
<td>g</td>
</tr>
</tbody>
</table>

   c. What is the direction of the flow of electrons in the wire? (mark one)
   Black to Red ______  Red to Black ______

   d. From your observation from the simulation, which metal in the diagram is the anode?
   (a or b) ______. Which one is the cathode? (a or b) ______. Write down half reactions for each electrode in the table.

   |                  | Half reaction at the anode: |
   |                  | Half reaction at the cathode: |

   Click on the “New Trial” button to start a new electrolysis experiment.

4. Set-up another electrolysis experiment and connect a **nickel** electrode and an **iron** electrode to a power supply and select **iron (II) nitrate** as the solution.

5. Select the mass of each electrode by dragging the slider and record the initial mass of each electrode.

6. Set the **voltage** and the **current** on the power supply. Select the amount of time you want the current to flow. Your goal is to set-up the electrodes so that **iron metal will be deposited on the nickel electrode** when the power supply is turned on.
e. Will nickel metal spontaneously react with aqueous iron (II) nitrate?
   Yes ______ No ______ Why?
   Please briefly explain (PLEASE PRINT)

f. Turn on the power supply. Observe what happen in the bath. At the end of the experiment, record the initial and final mass of each electrode in the table below.

<table>
<thead>
<tr>
<th>Metal on the red wire</th>
<th>Metal on the black wire</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial mass</td>
<td>Final mass</td>
</tr>
<tr>
<td>g</td>
<td>g</td>
</tr>
<tr>
<td>g</td>
<td>g</td>
</tr>
</tbody>
</table>

h. What is the direction of the flow of electrons in the wire? (mark one)
   Black to Red _____ Red to Black _____

h. From your observation from the simulation, which metal in the diagram is the anode? (a or b) _______. Which one is the cathode? (a or b) _______. Write down half reactions for each electrode in the table.

<table>
<thead>
<tr>
<th></th>
<th>Half reaction at the anode:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Half reaction at the cathode:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>
APPENDIX E. THE COVER PAGE OF CALIFORNIA CHEMISTRY DIAGNOSTIC TEST 1997

EXAMINATIONS INSTITUTE
I. D. EUBANKS, Director
L. T. EUBANKS, Associate Director

BOARD OF TRUSTEES
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JAMES G. HILL, California State U, Sacramento (Chair)
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LARRY S. MIYERS, California State U, Sacramento (Consultant)
M. PATRICIA NOEL, Harvard-Westlake School, CA
STEPHEN P. RUIS, American River College, CA
MAUREEN SCHABBURG, Sac State University, CA
FRED E. WOOD, University of California, Davis

TO THE EXAMINER: This test is designed to be taken with a special answer sheet on which the student records his or her responses. All answers are to be marked on this answer sheet, not in the test booklet. A pre-punched scoring stencil is available to facilitate grading. Each student should be provided with a test booklet, an answer sheet, and scratch paper, all of which must be turned in at the end of the examination period. The test is to be available to the students only during the examination period. For complete instructions refer to the Directions for Administering Examinations. Only non-programmable calculators are permitted. Notes are forbidden.

Score = Number of right answers
44 items — 45 minutes

TO THE STUDENT: DO NOT WRITE ANYTHING IN THIS BOOKLET! Do not turn this page until your instructor gives the signal to begin. When you are told to begin work, open the booklet and read the directions on page 2.

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## APPENDIX F. COMPOSITE NORMS CALIFORNIA CHEMISTRY

### DIAGNOSTIC TEST 1997

<table>
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<th>Score</th>
<th>Percentile</th>
<th>Score</th>
<th>Percentile</th>
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</tr>
<tr>
<td>30</td>
<td>88</td>
<td>15</td>
<td>26</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Mean: 20.45

Std deviation: 7.56

Median: 19.8

KR-21 rel: 0.83

Std error/means: 3.14
APPENDIX G. MOTIVATED STRATEGIES FOR LEARNING QUESTIONNAIRE

Please understand that you are not required to complete this questionnaire. Your grade in this course will not be affected whether you take this questionnaire or not.

Section I – Your Background

First Name: 
Last Name: 
Your ISU email address: 
Your lab section: 
Gender: 

Part A. Motivation

The following questions ask about your motivation for and attitudes about this class. Remember there is no right or wrong answers, just answer as accurate as possible. Use the scale below to answer the questions. If you think the statement is very true of you, clock 7; if a statement is not all true of you, click 1. If the statement is more or less true of you, find the number between 1 and 7 that best describes you.

Please use the following scale to rate your response:

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Not at all true of me</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Very true of me</td>
</tr>
</tbody>
</table>

1. In a class like this, I prefer course material that really challenges me so I can learn new things.
2. If I study in appropriate ways, then I will be able to learn the material in this course.
3. When I take a test I think about how poorly I am doing compared with other students.
4. I think I will be able to use what I learn in this course in other courses.
5. I believe I will receive an excellent grade in this class.
6. I'm certain I can understand the most difficult material presented in the readings for this course.
7. Getting a good grade in this class is the most satisfying thing for me right now.
8. When I take a test I think about items on other parts of the test I can't answer.
9. It is my own fault if I don't learn the material in this course.
10. It is important for me to learn the course material in this class.
11. The most important thing for me right now is improving my overall grade point average, so my main concern in this class is getting a good grade.
12. I'm confident I can learn the basic concepts taught in this course.
13. If I can, I want to get better grades in this class than most of the other students.
14. When I take tests I think of the consequences of failing.
15. I'm confident I can understand the most complex material presented by the instructor in this course.
16. In a class like this, I prefer course material that arouses my curiosity, even if it is more difficult to learn.
17. I am very interested in the content area of this course.
18. If I try hard enough, then I will understand the course material.
19. I have an uneasy, upset feeling when I take an exam.
20. I'm confident I can do an excellent job on the assignments and tests in this course.
21. I expect to do well in this class.
22. The most satisfying thing for me in this course is trying to understand the content as thoroughly as possible.
23. I think the course material in this class is useful for me to learn.
24. When I have the opportunity in this class, I choose course assignments that I can learn from even if they don't guarantee a good grade.
25. If I don't understand the course material, it is because I didn't try hard enough.
26. I like the subject matter in this course.
27. Understanding the subject matter of this course is very important to me.
28. I feel my heart beating fast when I take an exam.
29. I'm certain I can master the skills being taught in this class.
30. I want to do well in this class because it is important to show my ability to my family, friends, employer, or others.
31. Considering the difficulty of this course, the teacher, and my skills, I think I will do well in this class.
Part B. Learning Strategies

The following questions ask about your learning strategies and study skills for this class. Again, there are no right or wrong answers. Answer the questions about how you study in this class as accurately as possible. Use the same scale to answer the remaining questions. If you think the statement is very true of you, select 7; if a statement is not at all true of you, select 1. If the statement is more or less true of you, find the number between 1 and 7 that best describes you.

32. When I study the readings for this course, I outline the material to help me organize my thoughts.

33. During class time I often miss important points because I'm thinking of other things.

34. When studying for this course, I make up questions to help focus my reading.

35. I usually study in a place where I can concentrate on my course work.

36. When reading for this course, I make up questions to help focus my reading.

37. I often feel so lazy or bored when I study for this class that I quit before I finish what I planned to do.

38. I often find myself questioning things I hear or read in this course to decide if I find them convincing.

39. When I study for this course, I practice saying the material to myself over and over.

40. Even if I have trouble learning the material in this class, I try to do the work on my own, without help from anyone.

41. When I become confused about something I'm reading for this class, I go back and try to figure it out.

42. When studying for this course, I go through the readings and my class notes and try to find the most important ideas.

43. I make good use of my study time for this course.

44. If course readings are difficult to understand, I change the way I read the material.

45. I try to work with other students from this class to complete the course assignments.

46. When studying for this course, I read my class notes and the course readings over and over again.

47. When a theory, interpretation, or conclusion is presented in class or in the readings, I try to decide if there is good supporting evidence.

48. I work hard to do well in this class even if I don't like what we are doing.

49. I make simple charts, diagrams, or tables to help me organize course material.
50. When studying for this course, I often set aside time to discuss material with a group of students from the class.
51. I treat the course material as a starting point and try to develop my own ideas about it.
52. I find it hard to stick to a study schedule.
53. When I study for this class, I pull together information from different sources, such as lectures, readings, and discussions.
54. Before I study new course material thoroughly, I often skim it to see how it is organized.
55. I ask myself questions to make sure I understand the material I have been studying in this class.
56. I try to change the way I study in order to fit the course requirements and the instructor's teaching style.
57. I often find that I have been reading for this class but don't know what it was all about.
58. I ask the instructor to clarify concepts I don't understand very well.
59. I memorize key words to remind me of important concepts in this class.
60. When course work is difficult, I either give up or only study the easy parts.
61. I try to think through a topic and decide what I am supposed to learn from it rather than just reading it over when studying for this course.
62. I try to relate ideas in this subject to those in other courses whenever possible.
63. When I study for this course, I go over my class notes and make an outline of important concepts.
64. When reading for this class, I try to relate the material to what I already know.
65. I have a regular place set aside for studying.
66. I try to play around with ideas of my own related to what I am learning in this course.
67. When I study for this course, I write brief summaries of the main ideas from the readings and my class notes.
68. When I can't understand the material in this course, I ask another student in this class for help.
69. I try to understand the material in this class by making connections between the readings and the concepts from the lectures.
70. I make sure that I keep up with the weekly readings and assignments for this course.
71. Whenever I read or hear an assertion or conclusion in this class, I think about possible alternatives.
72. I make lists of important items for this course and memorize the lists.
73. I attend this class regularly.
74. Even when course materials are dull and uninteresting, I manage to keep working until I finish.
75. I try to identify students in this class whom I can ask for help if necessary.
76. When studying for this course I try to determine which concepts I don't understand very well.
77. I often find that I don't spend very much time on this course because of other activities.
78. When I study for this class, I set goals for myself in order to direct my activities in each study period.
79. If I get confused taking notes in class, I make sure I sort it out afterwards.
80. I rarely find time to review my notes or readings before an exam.
81. I try to apply ideas from course readings in other class activities such as lecture and discussion.

Thank you for taking the Motivated strategies for Learning Questionnaire (MSLQ).
APPENDIX H. TABLES OF RELIABILITY ANALYSIS, COVARIATE ANALYSIS, AND REGRESSION ANALYSIS OF TEST AND QUESTIONNAIRE ITEMS

Table 1.

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<th>Scale Mean if Item Deleted</th>
<th>Scale Variance if Item Deleted</th>
<th>Corrected Item-Total Correlation</th>
<th>Squared Multiple Correlation</th>
<th>Alpha if Item Deleted</th>
</tr>
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*Reliability Analysis of Test Items*

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Tukey estimate of power to which observations must be raised to achieve additivity

= .6427

Reliability Coefficients: Alpha = .7023

18 Items Standardized Item Alpha = .7473
### Table 3.

*Correlations of the MSLQ Items*

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Table 4.

*Number of Correct Answers for Each Test Item and Item Significance*

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Table 5.

*Covariate Analysis of Treatment Effect, Gender, Prior Knowledge, and the Interactions of the Independent Variables*

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*Note.* Computed using alpha = .05. $R^2 = .410$ (Adjusted $R^2 = .362$).
Table 6.

Regression Analysis of MSLQ Items

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a. Predictors: (Constant), Motivation Total.

b. Predictors: (Constant), Motivation Total, Strategy Total.

c. Dependent Variable: Item Total (22, 23, 24, 25 removed).
ACKNOWLEDGEMENTS

I had never thought I could go this far before the year of 1999. I would first like to express my gratitude to both my major professors, Dr. Andre and Dr. Greenbowe, who guided me through the journey to a PhD and also to other committee members for their wonderful suggestions to my dissertation. My appreciation also goes to the wonderful friends I met in Ames. They are the people from all over the world who shared their beautiful minds with me during these years of pursuing my degree at Iowa State University. Most of all, I want to thank my wife, Hsueh-Hua, who challenged and encouraged me during the ups and downs of my dissertation work. I would not have been who I am today without her support and love. Living in Ames is a wonderful and unforgettable experience in my whole life. I will never forget the days in this small but vivid college town with my wife and my little boy, Matthew. Thank you too, Matt!

To my parents, especially my mother who passed away three years ago, thank you for your silent yet endless love.