COMPUTER-ANIMATED INSTRUCTION AND STUDENTS' ACHIEVEMENT GAINS IN ELECTROCHEMISTRY

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DECLARATION

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ABSTRACT

This study compares the effects of computer-animated instruction (CAnI) and conventional-based instruction (CBI) on students' conceptual change. The subjects, 85 matriculation students from the International Islamic University (IIU), Malaysia were taught the fundamentals of electrochemistry. They were randomly assigned to a CAnI (N=45) or a CBI group (N=40). The CAnI group received lessons through computer-animated presentation and collective discussions, while the CBI group received lessons through the teacher's explanation and presentation using overhead prepared transparencies. A combination of questionnaires, pre-test and post-test scores and interview transcripts was used to analyze subjects' conceptual change and perceptions towards CAnI and CBI respectively. The questionnaire analysis revealed that students in the CBI group considered the teacher's direct transmission approach aided by transparencies with emphasis on explaining simple facts as the most helpful aspect to improve their understanding of electrochemistry concepts, while the students in the CAnI group clearly believed that the systematic step-by-step discrete sequences of animation as the most helpful aspect of their teacher's presentation. The overall pre-test and post-test analyses revealed that the students in the CAnI group experienced stronger conceptual change compared to the subjects in the CBI group. The answers given by the interviewees in the CAnI group improved dramatically in the post-test, thus showing evidence of their stronger conceptual change in comparison to the students who were exposed to the CBI. The findings also revealed that subjects in both groups experienced weak conceptual change as they failed to deeply understand the structure of some conceptually complex questions. However, the overall answers given by the CAnI

group in the post-test and during interviews tended to display more correct logical sequence in their use of concepts, thus showing evidence of their stronger conceptual change in comparison to the students who were exposed to the CBI. These results show clear evidence that the CAnI approach is more successful in the fostering of higher order learning than the conventional CBI, and thus supports the assertion that CAnI is an effective instructional means to enhance students' strong conceptual change and deeper understanding.

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TABLES OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

BACKGROUND OF THE STUDY

Teaching and Learning in Science Education in Malaysia

Malaysia has given a high priority to educational development since independence in 1957. The post-independence concerns were to create a national identity and to expand the educational system with the aim of "eradicating poverty and redressing the economic imbalance among races" (Lee, 1992, p. 253). The emphasis on science education started in 1960 in response to reports by the Education Review Committee which called for explicit commitment to improve the quality of science education (Zain & Lewin, 1993). In the 1960s, General Science was taught as a compulsory subject at the lower secondary level. Since then, science education in Malaysia has undergone several changes and innovations.

In 1968, the Ministry of Education (MOE), Malaysia was concerned with the poor performance of the pupils in the rural primary schools, particularly in science and mathematics. The MOE then began science curriculum reforms with the introduction of *Projek Khas* (literally "Special Project"). This project aimed to improve primary pupils' performance in school science and mathematics, so that children would develop a better understanding and a positive attitude towards the science and mathematics subjects (Lee, 1992). Under this project, teaching notes and guides were published in order to assist science and mathematics teachers in their delivery of an inquiry led approach to learning.

Then in 1969, the MOE through the Curriculum Development Centre adapted the Scottish Integrated Science Syllabus for lower secondary school science (Form I, II and III) to replace the existing General Science subject. Subsequently, in 1972, the newly-formed Curriculum Development Centre (CDC), introduced new science subjects for Forms IV and V - Modern Physics, Chemistry and Biology which were derived from Nuffield Science materials from England. For upper secondary non-science stream students, the Modern Science subject was introduced in 1974, derived from Nuffield Secondary Science (Lee, 1992). As stated by Zain and Lewin (1993), these new science subjects emphasized student-centered approaches based on guided-inquiry methods.

The teaching and learning strategies for science subjects which utilized guided-inquiry continued with the implementation of the New Integrated Secondary School Curriculum (Kurikulum Bersepadu Sekolah Menengah, KBSM) in 1989. Specifically, science in the KBSM stressed the development of scientific skills through guided-inquiry activities where students are actively involved in solving and discovering scientific phenomena through investigations, discussions, and problem solving (Ministry of Education [MOE], 1994a).

Guided-inquiry as introduced to Malaysian teachers is an approach where "the teacher acts as a resource person, giving only sufficient help just enough for the students to go with the inquiry" (Johar, Halim & Othman, 2004). Therefore in daily practice, guided-inquiry is implemented mostly for doing experiment where the teacher provides the materials and problem for the students to investigate, emphasizing the scientific process skills such as observation and data collection. Teaching modules such as *Kemahiran Proses Sains* (Science Process Skills) (MOE, 1996), *Kemahiran Berfikir* (Thinking Skills) (MOE, 1994b) and *Pengoperasian Kemahiran Proses Sains dalam Pengajaran dan Pembelajaran* (The Operation of Science Process Skills in Teaching and Learning) (MOE, 1996) are provided by the MOE through the Curriculum Development Center in order to foster and implement the guided-inquiry approach.

Realizing that learning science is more than acquiring science process skills, the MOE took the step of introducing the constructivist learning theory in 2001, to highlight the importance of student's active engagement in constructing personal meaning of the subject matter. As stressed by Martin (2003), constructivist learning gives emphasis to an active search for meaning and understanding by individual students where they construct deep understanding through social activities and interaction with others. This approach takes into consideration students' prior knowledge, beliefs and attitudes as well as encourages discussion in order to help them acquire new concepts (MOE, 2001b). The constructivist approach has of course been interpreted in many different ways; the MOE's interpretation is the model shown in Figure 1.

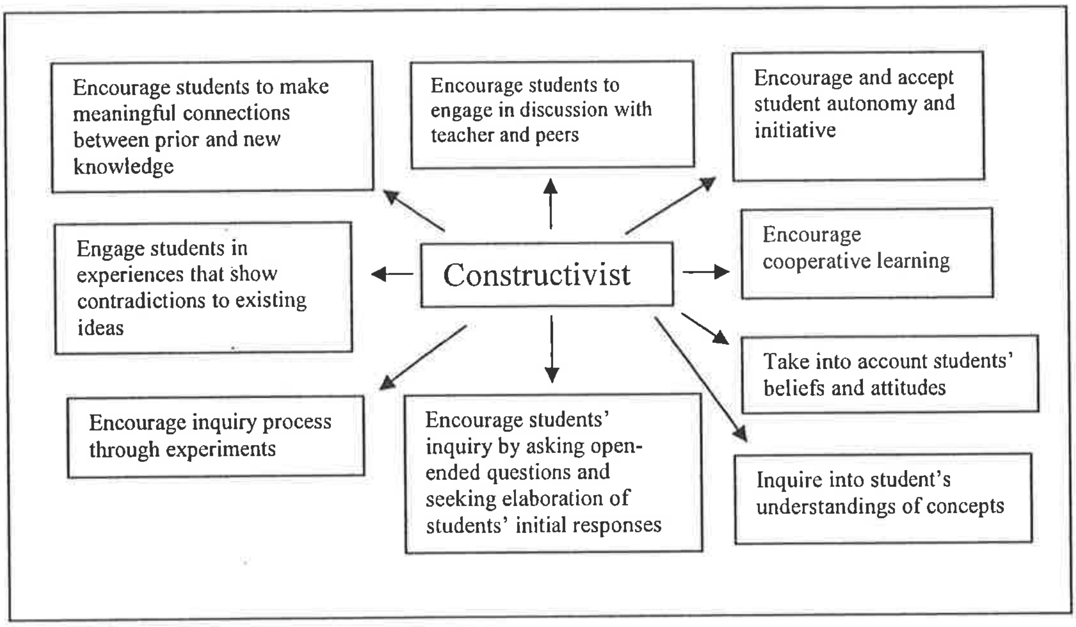


Figure 1. Characteristics of constructivist-informed teaching and learning (MOE, 2004b).

Figure 1 lists nine characteristics of conducting constructivist teaching and learning in the classroom. For example, teachers should be able to encourage students' inquiry by asking open-ended conceptual questions or encourage cooperative learning to foster evaluation of students' ideas, particularly if these ideas conflict with each other. Four strategies are suggested in implementing constructivist teaching and learning (MOE, 2004b):

1. Take into account students' prior knowledge.
2. Learning occurs as a result of students' own effort.
3. Learning occurs when students restructure their existing ideas relating new ideas to old ones.
4. Provide students with opportunities to cooperate, share ideas and experiences, and reflect on their learning.

In comparison to the guided-inquiry practice in Malaysia which focuses on science process skills, the constructivist approach gives focus on reconstructing and reinterpreting current ideas in order to reconcile them with new information (MOE, 2001a). This is one of the important implications of the constructivist approach in science teaching. Therefore, one of the teacher's roles is to diagnose students' prior knowledge on the topic through carefully-planned constructivist activities such as interviews, asking questions, group discussions or through computer technologies.

The application of computers in the classrooms of Malaysia is understood to be a key driver in delivering the instructional shift from transmissive and guided inquiry to a more constructivist approach (Fong-Mae, 2002). Such educational reform started in 1998 when the Ministry of Education launched the Smart School project in order to enable teachers and students in Malaysia to utilize the advantage of information technology at all levels of education. This project involves the use of computer technology as a powerful tool in enhancing the effectiveness of teaching and learning science (Fong-Mae, 2002). The launching of the Smart School project in tandem with curriculum subjects "be[ing] taught using multimedia technology" and "computer-assisted learning be given the necessary thrust", showed the seriousness of the MOE to revolutionize education and improve learning (MOE, 1999, p7). The application of computer technologies in the classroom, as stated by Neo and Neo (2002):

> …can be used by the teacher to represent and support his or her educational material…stimulate their [students] learning process and make them active participants in meeting their learning objectives. (p. 142)

One way teachers can take into account the students' current understanding is through computer applications such as animation, which offer great potential for bridging the gap between what their students already know and the targeted concept being discussed. For example, the teacher can show an explicit animation of an electrolytic cell so that the students can visualize the abstract and dynamic chemical processes that occur in the cell. As stressed by the MOE (2004, p. 14), "computers are effective tools for the teaching and learning of abstract or difficult science concept."

It is also difficult for students to comprehend and construct the accurate mental models required to understand the abstract concepts that involve unobservable particles such as electrons, ions and atoms. Sanger and Greenbowe (1997a) observed that in Chemistry lessons many students failed to visualize chemical reactions as dynamic processes at particulate level from experiment or static illustration. It is argued in this study that utilizing constructivist techniques, aided by computer generated animations, will provide a superior method of presentation than those delivered by conventional teaching. The incorporation of dynamic animation goes beyond the explanatory notes written on transparencies or the blackboard.

Focus of the Study

The focus of this study will be on chemistry concepts, more specifically, the concepts of electrochemistry. The Curriculum Development Centre (a unit in the MOE) published a module, entitled *Pembelajaran Secara Konstruktivisme* (Learning through Constructivism), to encourage teachers to apply constructivist teaching and learning activities during chemistry lessons (MOE, 2001b). In the Malaysian educational system, chemistry contents are currently integrated and taught within the Science subject at primary, lower and upper secondary levels. Chemistry contents are also taught for non-science students as part of General Science and Additional Science at the upper secondary level, while for science students at this level too, Chemistry is taught as one of the core single subjects and reemphasized at the post secondary level. For example, students in Malaysia start to learn the basic principles of electrochemistry in chemistry class at the upper secondary level and are exposed to the topic in greater depth at the pre-university level.

Basically, it is relatively easy for students to discover simple basic concepts in chemistry through the guided-inquiry approach such as the determination of pH properties based on color change interval using pH paper. However, previous studies conducted by Garnett and Treagust (1992); Huddle and Margaret (2000); Ozkaya (2002); Sanger and Greenbowe (1997a, 1997b, 1999) found that a majority of students had difficulty understanding abstract and dynamic concepts such as electrochemistry. Moreover, Chemistry is known as a very difficult subject to comprehend because most chemical concepts are presented at the symbolic, macroscopic and microscopic levels of abstractness (Kozma & Russel, 1997).

An important issue here is how students can understand chemistry concepts because they possess different levels of abstractness (Taber, 2000). For example, at the symbolic level of abstractness, students are able to recall an electrolyte as 'a substance that dissociates into free ions when dissolved (or molten), to produce an electrically conductive medium.' However, recalling the definition is not enough to construct an accurate mental model at the macroscopic and microscopic level of abstractness on how an electrolyte, which consists of ionic particles, demonstrates electrical conductivity in electrochemical cells. Such ideas must be presented in a meaningful way by the teacher in order to bridge the gap between students' current ideas and a desired idea needed to understand the concepts. Therefore, instead of relying on the guided-inquiry approach, the teacher should also consider the constructivist approach to teaching and learning chemistry.

The teacher's presentation of the target concept is crucial in facilitating students' understanding. Other than understanding how students' alternative conceptions hinder their learning process, the teacher should also know how to challenge and facilitate students to develop scientific understanding as accepted by scientists. The teacher needs to design and organize instructional activities and materials in order to prompt the students to restructure their alternative conceptions and provide active mental engagement activities through explicit visual representations of the targeted concepts. One way of doing this is by designing systematic step-by-step animation presentations. Such animation is aligned with the constructivist view which postulates that knowledge is constructed when the material given is meaningful, especially when the animation is designed to visualize chemical processes at the particulate nature of matter (Burke, Greenbowe & Windschitl, 1998) thereby providing opportunities for students to gain deep understanding.

While computer technologies have the potential to be integrated with the constructivist derived approaches, they also place specific demands on teachers to choose or develop the appropriate computer presentations that facilitate a student's own understanding through activities and interaction during science classes. For this proposed shift of instructional method to occur, new instructional materials need to be designed and tested. Research is needed to investigate how to integrate the latest computer technologies within a constructivist mode consistent with the objectives of chemistry education in Malaysia. This then is the intention of this study; to design an animation aided constructivist approach to instruction and to test its implementation in the Malaysian context.

STATEMENT OF PROBLEM

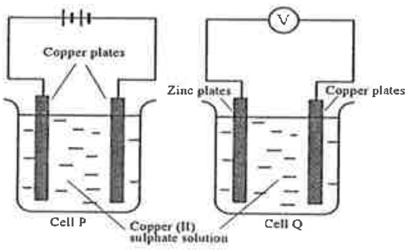
Science education in Malaysia in general has been in the limelight mainly due to the many negative testimonies on the outcomes of science learning. Reports done by the Examination Syndicate Ministry of Education Malaysia regarding the chemistry performance in the Malaysian Certificate of Education examination for example, found that most students failed to acquire basic conceptual understandings (MOE, 2004a) but were able to provide answers for questions requiring simple recall of scientific facts, had problems with analyzing abstract processes and failed to classify, synthesize and evaluate information.

Specifically in chemistry education, one of the current aims of teaching chemistry in Malaysia is to provide students with the knowledge and skills that would enable them to solve problems from specific types of calculations to open-ended situations. However, the latest findings of the *SPM Performance Report 2003* (MOE, 2004a) by the Examination Syndicate regarding the chemistry performance in the Malaysian Certificate of Education examination are incongruent with this aim. It was found that the "majority of candidates did not understand and master the concepts of chemistry" (MOE, 2004a, p.14). In particular, the report found weaknesses in the answering of electrochemistry-related questions and concluded that the majority of candidates failed to acquire basic conceptual understandings (MOE, 2004a).

Table 1 shows the actual questions and weaknesses analyzed by the Examination Syndicate. The analysis showed that even after instruction and long preparation for examination, the majority of chemistry candidates had difficulties in understanding the fundamentals of electrochemistry.

Table 1

Analysis of Candidate's Weaknesses in Electrochemistry Questions for SPM 2003.

Section C, Question 3	
Actual questions	Reported weaknesses
a. Lime juice was electrolyzed using carbon electrodes. What is produced at the cathode? Write a half-equation for the reaction. b. Figure 6 shows two types of cell. Compare and contrast cell P and Q. Include in your answer the observation and half-equations for the reactions of the electrodes in both cells.  c. A student intends to electroplate an iron key with a suitable metal to beautify it. Design a laboratory experiment to electroplate the ion key. Your answer should address the following: • Chemicals required • Procedures of the experiment • Diagram showing the set-up of the apparatus • Chemical equation involved in the reaction • Observations	a. Many candidates failed to write a balanced half-equation. b. Many candidates failed to: - take the nature of electrodes into account - list all ions that exist in the solution - write a balanced half-equation - write a correct half-equation - determine the anode and the cathode - mention the change of colour for the solution c. Many were able to set up the experiment but failed to: - use a suitable metal and solution - draw batteries - identify an iron key as cathode - determine the anode and the cathode - list observations such as the formation of precipitation - write correct ionic charge - write lead and nickel ions as Ag^{2+} and Ni^{+} - use carbon, magnesium and ferum as electroplating metal

In addition to the weaknesses reported by the Examination Syndicate, a study by Che Lah and Loke (2004) revealed that secondary students in Malaysia have difficulties in proper understanding of abstract electrochemical processes, such as:

1. Students think that two different metals are used in a galvanic cell because they have different electrical charges.
2. Students know that electrons should be written in half-equations but do not know how to write the equation.

3. Students are confused when identifying an electrode as anode or cathode.

Other than the problems mentioned above, Zain and Lewin (1993) in their comprehensive studies on science education in Malaysia noted that in reality, science teachers in Malaysia operate under the paradigm 'to cover the syllabus' for the purpose of 'to do well in the examination'. The studies found that science teachers utilized exam-oriented teaching methods that merely emphasized rote learning.

Recent research by Daud (2003) revealed that a majority of chemistry teachers in Malaysia use the direct transmission approach to explain and draw electrochemical cells, whilst students passively listen and take notes. He stated that chemistry teachers preferred to use only the blackboard to illustrate static images of the electrons and ions involved in the electrolysis process. Some teachers used chalk drawing and oversimplified illustrations of electrochemical phenomena to make them easier to remember. Furthermore, there were cases where chemistry teachers tried to cover the syllabus as quickly as possible in order to give more attention to tackling examination questions. Most science teachers in Malaysia are known to practice the direct transmission approach where students function largely as passive recipients of the knowledge (Daud, 2003). These views are consistent with those of Hutchinson (2000, p.3), when he claimed that in general, chemistry in the United State of America is taught to students mostly based on "expository and explanatory statements of concepts and applications...clearly the pervasiveness of traditional approach."

As stated by Daud (2003), although the constructivist strategies are encouraged by the MOE, the traditional direct transmissive approach is widely practiced by chemistry teachers in Malaysia where students function largely as passive recipients of knowledge. Perhaps the phenomenon of practicing the transmissive approach is also influenced by the pressure of the national examinations, which maintain the examination-oriented culture in the Malaysian school system (UNESCO, 2003). In the Malaysian context, the national examinations may be understood to generate an exam-oriented pressure urging teachers to focus more on the techniques of answering set questions and to complete the syllabus as quickly as possible. Furthermore, sitting for at least four national examinations encourages Malaysian students to rote-learn subject contents merely to pass these examinations and fosters little intrinsic interest in the learning process.

Instead of the direct transmission approach widely used in classroom, the guided-inquiry approach as encouraged by the MOE is mainly implemented in science laboratory activities. This approach is used to enhance student's performance in the process skills but not too much in conceptualizing scientific phenomena. In one study conducted by the Division of Planning and Research for Educational Practice in 1977, the MOE revealed that most schools in Malaysia do not have enough equipment for conducting experiments or are using old and outdated equipment. This is why most schools are only interested to conduct selected guided-inquiry experiments for the purpose of answering examination questions rather than to develop students' process skills or conceptualizing scientific phenomena. The findings also revealed that laboratory work was conducted by just following experiment manual. It can be argued whether the direct transmission approach and the minimum implementation of guided-inquiry in the laboratory could bring student to strong conceptual change and go beyond rote memorization. Therefore in such situations, the implementation of constructivist strategies for conceptual change in teaching and learning science which emphasizes an active search for meaning and understanding by individual students is crucial in the context of Malaysian science education system. By doing so, students are engaged in learning that involves them in constructing personal meaning for conceptual change of the subject matter.

RATIONALE FOR STUDY

Realizing that in teaching science subjects in the classroom such as Chemistry, teachers in Malaysia are "stuck" within the direct transmission approach and that the MOE is calling for them to shift to instructional methods that are constructivist and IT rich, this study offers the design and testing of an approach consistent with this call; an approach that integrates step-by-step discrete sequences of computer animation within a constructivist method of instruction, namely computer-animated instruction (CAnI).

The direct transmission approach normally involves giving lectures about scientific concepts and facts, and typically engages students on a weak conceptual change or surface level. Since it is challenging for science teachers to guide or facilitate students towards strong conceptual change, it is believed that the use of computer-animated instruction, CAnI, will provide viable solutions for engaging students in the constructivist instruction approach. This study has carefully chosen the conceptual change model, in order to test the CAnI technique against the conventional direct transmission approach intentionally along the axis of weak conceptual change (surface understanding) to strong conceptual change (deep understanding).

To date, no study has been done in Malaysia on chemistry instruction attempting to measure students' conceptual change. Therefore, this study is anticipated to provide information and guidance for teachers and policy makers on how the constructivist approach using computer-animated instruction can be used to enhance students' conceptual change and whether or not it may be an effective technique in the Malaysian context. Furthermore, there is no literature currently available in the Malaysian context that specifically addresses the conceptual change strategy in chemistry instruction which optimizes the use of educational courseware to portray complex, abstract and dynamic chemical processes at the microscopic level of presentation. Most of the educational courseware developed for chemistry education, particularly in Malaysia, are self-paced multimedia packages. Such courseware relies on students working alone with little teacher intervention (Kennedy & McNaught, 1996).

It is believed that the use of computer-animated instruction in a lecture format that presents chemical understandings at the symbolic, macroscopic as well as microscopic levels is a promising means to foster effective teaching and learning in chemistry education. Furthermore, the increasing availability of advanced developer- and learner-friendly authoring software has enabled the possibility of computer animation being widely integrated into chemistry instruction across the country. When this format is aided by guided collective discussion as part of the instructional delivery, it is hoped that CAnI may well be a timely and effective addition to assist Malaysian teachers in achieving the pedagogic shift that the MOE is requiring of them. It is also hoped that the CAnI technique may be transferable to other constructivist settings outside of the Malaysian context. Given that the constructivist and IT rich trends are now promoted in many parts of the world, this seems a possibility worthy of future exploration.

THEORETICAL FRAMEWORK

In this section, there is a brief introduction to constructivism and the conceptual change model. An introduction to computer animation and theoretical framework is also presented.

Constructivism and Conceptual Change Model

Catherine T. Fosnot in her book entitled *Constructivism: Theory, Perspectives and Practice*, described constructivism as "…a theory about knowledge and learning; it describes both what *knowing* is and how one *comes to know*" (Fosnot, 1996, p. ix). Although constructivism is not a theory of teaching, the movement from traditional direct transmission to constructivist instructional approaches in recent literature (Azzarito & Ennis, 2003; DiPietro, 2004; Elby, 2000; Jenkins, 2000; Jones & Brader-Araje, 2002; Martin, 2003; Moallem, 2001; Neo & Neo, 2002; Taber, 2000) reflects the movement from the teacher transmitting information to students to the teacher facilitating students in the active pursuit of furthering their own knowledge.

Studies in science education have shown an impressive influence from the constructivist perspective, across the whole range from elementary to tertiary levels of education. The most important element of constructivist learning theory is that learners actively construct their own knowledge based on their existing ideas or prior knowledge through physical and social interactions with the environment (Fosnot 1996; Glasersfeld, 1987, 1995).

Teaching for conceptual change is drawn from Piaget's perspective of the learning process. Piaget (1977) referred to the process of integrating and fitting new ideas or new experiences into existing ideas as "assimilation" and the process of modifying or splitting existing schemes as "accommodation." In other words, assimilation involves the incorporation of new information or experiences into the learner's existing cognitive structures while accommodation means existing cognitive structures change to accommodate the new information. Therefore, the instructional process to facilitate conceptual change must identify and highlight students' existing conceptions, provide opportunities for the ideas to restructure and finally enable students' new ideas to be applied such as in solving problems. This conceptual change model will be discussed in detail in the literature review in Part I.

In science education, where knowledge is well-developed and highly structured (West & Pines, 1985), conceptual change plays an important role in understanding the construction of knowledge (Hewson, 1992). Realizing that science concepts may not always be compatible with students' existing ideas, Posner, Strike, Hewson and Gertzog (1982) and Strike and Posner (1992), through their conceptual change model, argued that conceptual change can be promoted when students are dissatisfied with their current understanding and feel that their current understanding must be changed for a better conception. For the authors, students are likely to accept new ideas if they are unsatisfied with their own current understanding and feel that the understanding must be changed.

Posner et al. (1982) and Strike and Posner (1992) argued that new conception must meet at least three conditions before conceptual change can take place. The new conception must be intelligible (understandable and makes sense to the learner); plausible (appears reasonable as well as believable) and; fruitful (practical and useful to solve problems). In other words, teachers must present intelligible, plausible, fruitful learning materials in such a way that induces meaning between the students' existing ideas and the new ideas being taught.

Computer Animation

The incorporation of computer-aided instruction or computer-based instruction is an increasing phenomenon in classrooms around the world as schools and universities expand their IT facilities. Conventional forms of teaching have to adapt to accommodate this new influence because computer-aided instruction is now widely recognized as an effective way to teach and learn, not only through verbal presentation but also through dynamic forms of visual presentations. In particular to chemistry education, most conventional instruction emphasizes symbolic representations (such as balancing equations, stoichiometric calculations) and macroscopic representations (such as color changes, changes in state, heat changes), leaving the microscopic or molecular representations unexplored (Greenbowe, 1994). As a result, it is commonly found that many "students have difficulty thinking about chemical processes at the molecular level" (Greenbowe, 1994, p. 556). Therefore, he suggested that computer animations could be used as an effective tool in presenting chemical processes at the microscopic level, as well as at the symbolic and macroscopic levels. For him, viewing dynamic animations could help students properly link these three levels of understanding especially when learning complex, dynamic and abstract chemical processes.

Indeed, the integration of computer animation in science instruction has been proposed by many researchers as providing a teaching and learning tool that can facilitate students' conceptual change (Barnett, Keating, Barab and Hay, 2000; Sanger & Greenbowe, 2000; Tao & Gunstone, 1999; Windschitl & Andre, 1998). Specifically, the use of computer animation is believed to provide an opportunity for the students to organize and comprehend the sequences of the abstract, dynamic and complex processes (Allendoerfer, 2003; Jimoyiannis & Komis, 2001; Reid, Zhang & Chen, 2003). For example, animation can be used by chemistry teachers to show the donation of electrons during the process of electrolysis. Burke, Thomas, Greenbowe and Windschitl (1998) when referring to studies by Sanger and Greenbowe (1997a) argued:

> …because students often have difficulty visualizing, understanding, and remembering how dynamic chemical processes occur, the use of computers to display dynamic motion offers to help students understand complex chemistry concepts…communicate abstract ideas,

concepts and processes…at the atomic or molecular level of presentation. (p. 1658)

From the constructivist perspective, computer animation provides a situation in which students can visualize the connection between their existing ideas and the new information that enhances conceptual change. A study by Sanger and Greenbowe (2000) found that the use of animation in chemistry lessons was significantly preferable over conventional transparencies. They added that presenting computer animation would generate students' curiosity and positive attitudes towards learning. The authors then suggested that animation is effective in displaying dynamic motions of chemical processes which can enhance student' understanding of complex, abstract and dynamic concepts of electrochemistry.

Theoretical Framework of Current Study

Figure 2 illustrates the theoretical instructional framework on which the present study is carried out. This theoretical instructional framework is proposed by the researcher based on the assumptions offered by constructivist teaching for conceptual change. It consists of three phases, namely **Identification Phase, Induction Phase** and **Integration Phase.** The framework suggests that teaching for conceptual change requires the teacher consider students' existing ideas as well as engage them in the knowledge construction activities.

Identification Phase
Ask guided questions / discrepant events to identify learner's existing idea about specific conceptions and give opportunity to evaluate his/her ideas through collective discussion.

↓

Induction Phase
Present intelligible, plausible, fruitful new ideas and provide guidance / scaffold in such a way that induce meaning between learner's existing ideas to the new ideas.

↓

Integration Phase
Integrate learning tasks for learner to reflect and evaluate his/her new understanding

Figure 2. Proposed theoretical framework of the current study.

These three phases of instructional sequences serve three purposes that are:

1. Identifying students' existing ideas.
2. Inducing student's self-awareness of any cognitive conflict in their mind.
3. Integrating new ideas into students' cognitive structure by providing guidance or scaffold with aid of explicitly designed animations.

Each stage will be explained in the following paragraphs.

Identification Phase: In the identification phase, the teacher introduces discrepant events or guided equations and encourages students to search for a suitable explanation. Hence, it is intended that students may experience cognitive conflict about the concepts being taught, feel dissatisfied with and become aware of their own misconceptions. Then a 'collective discussion' is conducted to elicit students' current understanding. During the discussion, students are asked to give their own views on specific concepts under discussion and to communicate their reasoning to support their answers. This involves an explication of reasoning through explanation and argumentation under the teacher's guidance. The discussion is conducted based on the following guidelines:

1. Highlighting discrepant events or probing questions on specific concepts of discussion.
2. Asking students to give their own views.
3. Asking students why they think that is the answer.
4. Involving students in a collective discussion.
5. Encouraging students to discuss the pros and cons of their answers.

Inductive Phase: In the inductive phase, the teacher must present intelligible, plausible, fruitful learning materials in such a way that induces meaning between the students' existing ideas and the new ideas being discussed. At the same time, the teacher must provide links or connections between the new and existing information in order for the students to reconcile any misconception. In this study, computer animation is used to present the intelligible, plausible and fruitful learning materials.

Integration Phase: In the integration phase, students are encouraged to reflect and evaluate how their existing ideas or understanding have changed or restructured. Here, computer animation is used to provide a situation in which students can 'see' the connection and the logic between their existing ideas and new information presented to them so that the correct understanding will emerge.

The teaching phases mentioned above are believed to promote students' awareness of their own ideas as well as their active engagement and enhance conceptual change. These activities are consistent with the constructivist view of learning that emphasizes linking students' existing ideas with the new materials. In the collective discussion for example, the teacher asks probing questions for the students to consciously reflect their current knowledge individually or in the group.

Realizing that students come to the classroom with their own alternative ideas about science concepts, the teachers' crucial responsibility is to employ teaching strategies that can identify as well as resolve these alternative ideas. It is argued that this can be done through students' active participation in collective discussions and their engagement with animations designed to be intelligible and plausible learning materials.

OBJECTIVES OF THE STUDY

The main purpose of this study is to compare the effects of computer-animated instruction (CAnI) and conventional-based instruction (CBI) on the conceptual change of matriculation science students. An additional goal of this study is to provide Malaysian chemistry educators with a prototype computer-animated instruction methodology for promoting successful conceptual change with their students. The theoretical framework of conceptual change underpinning the implementation of a constructivist approach in this study was inspired by the model proposed by Posner et al. (1982). This conceptual change model is one of the most extensively researched theories that seek to understand students' conceptual learning (Gabel, 1999; Hewson, 1992; Huddle & Margaret, 2000; Ozkaya, 2002; Taber, 2000).

It is argued that the way chemistry teachers teach is often influenced by their experience as a student (Wang, 2004). For example, many of them perceived conducting demonstration or experiment activities as being enough for inquiry activities (Tuan, Chin & Chen, 2005), even though conducting laboratory experiments may not necessarily contribute to strong conceptual change and deeper understanding of scientific concepts (Bell, Blair Crawford & Lederman, 2003). As stated by Scaife and Rogers (1996), many science teachers did not realize that students' understanding also depends upon the teacher's presentation of the teaching material. Appropriate structured tools, such as carefully designed animations are crucial to activate students in their thinking for discovery, and to help them conclude accurate mental connections essential for concept formation.

Even though some chemistry teachers are exposed to constructivist-based instruction such as conceptual change strategies, in practice they prefer the direct transmission mode of teaching or teacher-dominated direct instruction approach (Blair et al., 2003). Science instruction for these teachers is influenced by concerns to cover the syllabus and for students to score highly in every examination. They perceive other teaching approaches as difficult, time-consuming and requiring active participation from the students.

RESEARCH QUESTIONS

Quantitative and qualitative research approaches are utilized in order to achieve the objectives of this study as mentioned above. The quantitative analysis as reported in Part III, has two foci:

1. To determine the effectiveness of CAnI compared to CBI in improving students' achievement in electrochemistry test scores.
2. To explore students' perceptions towards CAnI and CBI respectively.

The following research questions are posed to address the above aims:

1. Did students who were exposed to CAnI have better post-test mean score than students who were exposed to CBI?
2. What were the students' perceptions towards CAnI and CBI respectively?

In addition to the research questions, fourteen hypotheses were constructed to test the effectiveness of CAnI. The hypotheses are described in Section 3.4 of Part III.

The qualitative analysis reported in Part IV, has two foci:

1. To examine the students' conceptual change during CAnI and CBI.
2. To explore students' perceptions towards CAnI and CBI respectively.

Specifically two research questions are posed:

1. To what extent did CAnI enhance students' conceptual change compared to CBI?
2. What were the students' perceptions towards CAnI and CBI respectively?

OPERATIONAL DEFINITION OF TERMS

The purpose of the operational definitions is to give a common understanding of the terminologies (in alphabetical order) used in this study.

Collective discussion involves an explication of reasoning through discussion and argumentation by a group of students to enhance the conceptual change and co-construction of knowledge under the teacher's guidance. Both terminologies (discussion and argumentation) are used synonymously in the current study. Collective discussion is conducted based on the following guidelines:

1. Highlighting discrepant events or probing questions on specific concepts of discussion.
2. Asking students to give their own views.
3. Asking students why they think that is the answer.
4. Involving students in discussion.
5. Encouraging students to discuss the pros and cons of their answers.

Computer-animated instruction (CAnI) refers to the computer animation integrated in constructivist chemistry instruction developed in this study. Computer animation refers to a systematic conceptual animation, constructed to manage the flow of information and to display the order of events or chemical processes at the symbolic, macroscopic and microscopic levels. In CAnI, systematic step-by-step discrete sequences of animation acts as a key instructional tool to enhance the discourse between instructor and students. Such animation is aligned with the constructivist view, especially when the animation is designed to visualize chemical processes at the particulate nature of matter (Burke, et al., 1998), thereby providing opportunities for students to experience conceptual change.

The animations were designed in accordance with certain lesson plans chosen from within a specific electrochemistry topic, with learning materials being presented using a laptop computer and data projector. Drawing on the animations, class activities are directed to promote students' awareness of their own ideas, asking for explanation of discrepant events and encouraging collective discussions. The teacher is required to explain the subject contents and then students are required to justify and communicate their understanding of the contents they have just learnt to the teacher and to their peers.

Conventional-based Instruction (CBI) refers to the traditional practice of direct transmission instruction using an overhead projector and prepared transparencies with texts, diagrams, and static illustrations to deliver knowledge. CBI is primarily based on the teacher's explanation and presentation using prepared transparencies. The lesson ends with a question-and-answer session through a teacher-dominated discussion. During the discussion, the teacher answers all questions given by students immediately.

Conceptual change can be defined as a process that involves the restructuring, modifying, reorganizing or refining of existing ideas, knowledge or concepts to account for new information (Nussbaum & Sinatra, 2003). As stated by Hynd (2003), in order for a concept to change, students must first consciously think about what they have in mind about the concept and how it can be engaged or linked to new ideas. In this study, evidence of conceptual change was obtained when the students' pre-test answers were compared to the post-test answers, in terms of the correctness and completeness of the answers.

LIMITATIONS OF THE STUDY

The samples for this study were selected from one matriculation college in Malaysia. Although the study was conducted under strict controlled conditions, the limited number of subjects used in this study does not represent the whole population of pre-university or matriculation students in Malaysia. Furthermore, the relatively small number of subjects could have also influenced the statistical analysis of the study. Therefore, the findings are unique to that particular matriculation college and are confined within the context in which the study was carried out.

It is assumed that the students involved in the study are intellectually mature enough to comprehend the concepts being taught. It is worth mentioning that the interviewees gave their full cooperation during the study. In addition, the scope of content covered in this study is limited to the fundamentals of electrochemistry, including:

1. Oxidation and reduction.
2. Oxidation agent and reduction agent.
3. Electrolytes.
4. Electrochemical series.
5. Electrolytic cells.

6. Factors affecting electrolysis of aqueous solution.
7. Galvanic cells.

It is also assumed that the students involved in the study are intellectually prepared to answer the pre-test and post-test in English because the Matriculation centre uses English as the medium of instruction and in examination questions. The actual interviews were conducted in the Malay language because it was believed using their first language would give a deeper insight into their conceptual understanding. Furthermore, having students respond to interview questions in their native language will create a more informal and non-threatening situation and is likely to elicit richer dialogue.

The total of 200 minutes in four 50-minutes lessons allocated was not sufficient to integrate all concepts in the lessons plans if conducted as normal classroom instructions. For the study, prepared transparencies or animations as well as handouts were given to the students so that they could concentrate on the teacher's explanation to gain a deeper understanding of the whole concepts. It should not be a problem because the students involved in the study had gone through the topic of electrochemistry when they were in secondary school.

Finally, this study does not examine all the possible methods of effecting conceptual change discussed in the literature, but focuses on students' conceptual change aided by computer animation and collective discussion strategies.

ORGANIZATION OF THE RESEARCH PORTFOLIO

This research portfolio contains six sections. These are an Introduction to the Portfolio; Part I - Literature Review; Part II – Development of the Computer-Animated Instruction; Part III - Quantitative Analysis; Part IV - Qualitative Analysis; and Conclusion to the Portfolio.

The introduction to the portfolio contains an overview of the Malaysian educational system, with a specific focus on science and chemistry education. It also includes the statement of problem, rationale for study, theoretical framework, objective of the study, operational definitions and limitations of the study. The remainder of the portfolio is outlined below.

Part I describes the literature and background theory of cognitive and social constructivism in science education. This leads to the discussion on conceptual change theoretical framework emerging from previous studies in science education. A critical review in computer-mediated instruction is then incorporated to illustrate the varieties of computer technologies used in teaching and learning science.

Part II describes the developmental description of the computer-animated instruction used in this study to generate a constructivist instruction in order to enhance students' conceptual change.

Part III discusses the experimental research design used in this study, research variables, research hypotheses, sampling method, instrumentations, and the validity and reliability of the testing instruments. The chapter then reports the analysis of the quantitative data, which explores students' perceptions towards CAnI and CBI respectively through closed questionnaires, and examines the quantitative data of students' pre-test and post-test mean scores.

Part IV discusses the research design and the procedure for interviews. Sampling procedures as well as the validity and reliability of testing instruments are also described. The chapter then presents the analysis of the qualitative data, which explores students' perceptions towards CAnI and CBI using open-ended questionnaires and examines the conceptual change generated under both methods.

The final chapter considers the summary and conclusions that can be drawn from the analysis of quantitative and qualitative data. These conclusions of the study are then linked to their implications for science education and for future study.

PART I

LITERATURE REVIEW

In this chapter, a literature review in support of the study will be carried out in the following seven areas: Constructivism and science education; Aspects of conceptual change; Computers in science education; Reasons for animation; Research related to Electrochemistry; Pedagogical implications for conceptual change; and Critiques of conceptual change. The literature covers only the most relevant aspects of teaching and learning in the field of science and chemistry education in order to provide an overview of the issues addressed.

1.0 Constructivist Theory of Learning

The constructivist theory of learning has been accepted as one of the dominant epistemologies which can be applied to develop theories of teaching and learning in science education (Dethlefs, 2002; Driver & Oldham, 1986; Duit, 1995; Haney, 2003; Martin, 2003). Recent literature in science education states that two pioneering figures, Piaget and Vygotsky are amongst the most significant theoretical pioneers (Epstein, 2003; Graffam, 2003; Haney, Czerniak & Lumpe, 2003; Nussbaum & Sinatra, 2003). Piaget's theory of cognitive development proposes that learner's construct their own knowledge through experience, which enables them to create schemas through assimilation and accommodation processes. In short, cognitive development emphasizes conceptual change as an interaction between the learner's existing schemas and new experience. Therefore, learning occurs when the learner integrates the new experience into existing cognitive structure in a meaningful way.

On the other hand, Vygotsky stresses the importance of social contexts in learning environments. He proposes that cognitive development is dependent on social interaction (Hausfather,1996), claiming that learning occurs in the Zone of Proximal Development (ZPD) or what he defines as "the distance between the actual development level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers" (Vygotsky, 1978). In learning perspectives, a student can solve a task under expert or teacher guidance or with peer collaboration that could not be achieved alone. Despite their differences, Piaget and Vygotsky agree that learning is the internalization of new experience using or mediated by the knowledge constructs previously established.

In the educational context, cognitive development can be understood as the learners' mental processes to understand information by restructuring their existing cognitive structure. In a classroom setting, learners restructure their existing cognitive structure individually through social interactions with teachers, peers and the environment. Specifically in science education, Driver and Oldham (1986) described that cognitive development is a continuous and active process that involves the construction of meanings by generating links between existing knowledge and the new phenomenon attended to.

1.0.1 Piaget's cognitive development theory

This study focuses on the essential aspects of cognitive development likely to be effective in implementing instruction needed by science teachers to facilitate students' conceptual change. As argued by Eggen and Kauchak (1997), MacBeth (2000), and Windschitl and Andre (1998), the cognitive development approaches in education began from the ideas of assimilation and accommodation highlighted by Piaget as previously mentioned. Gros (2002, p. 323) stated that although Piaget's works "concentrated on analyzing the relationship between a person and his/her environment", he "did not deny the role of the social world in the construction of knowledge." Piaget (1977) believed that children develop and organize information into groups of interrelated ideas in cognitive structure. This information according to Martin (2003, p. 181), "are linked to each other in ways that are unique to the individual." and continuously develop, restructure and enlarge through assimilation and accommodation processes. These mental adaptation processes have become general references to most current theories of cognitive development (Feldman, 2004) including conceptual change used in this study.

Assimilation is a process of adding new ideas or new experiences into existing schemes. In other words, knowledge construction results from mental processes when individual existing schemes interact with new experience. The more important process in terms of intellectual growth is accommodation, a process of modifying or splitting existing schemes into a new cognitive structure to accommodate new experiences or ideas. Although there are situations where new information does not fit with an existing cognitive structure, the learners will recreate their own mental models of reality. Therefore, assimilation of new information is only part of the process of learning because real learning occurs only when an individual can integrate the new experiences into existing schemes, and interprets these experiences in a meaningful way (Feldman, 2004).

Piaget (1977) also provided a theory on how a learner strives in search of meaning to understand new ideas and experiences through the process of equilibration. Equilibration is an inner drive or personal self-motivation to obtain optimum adaptation through the process of assimilation and accommodation. If the learner does not understand or fails to make sense of a new concept, the condition of mental disequilibration occurs. This situation is often called cognitive conflict by researchers such as Lee (2003), Limon (2001) and Niaz (1995). In this situation, the act of thinking for a solution takes place through assimilating and accommodating until a balance between the learner's scheme for understanding and the phenomena the world provides is achieved. In order to achieve equilibration, the schemes enlarge or split into new ones until the new ideas make sense.

Here, equilibration is a dynamic self-regulatory process driven to maintain mental equilibration accompanied by continuous knowledge development. This is how learning takes place for Piaget, by means of an assimilation-accommodation process in the learner's mind. In short, learning for Piaget is a dynamic process where learners accommodate what they already understand to what they are trying to comprehend.

Piaget's theory of cognitive development is useful in pedagogical practice. The works of Piaget are considered to be the foundation for the constructivist approach of learning and teaching in science education. Pedagogically, Piaget's views are also credited to the teaching for conceptual change. Zirbel (2005) for example, suggested that to understand new information, the student not only has to assimilate and accommodate more information but also has to work towards obtaining fluency in the newly learned concept. Making connections between various concepts meaningfully will bring to deep learning. Therefore, one of the crucial instructional strategies in science education is to show the relationship between various concepts to the students.

1.0.2 Vygotsky's social constructivism

Vygotsky, often referred to as a pioneer in social constructivism, emphasized language as the main medium in learning activities. He placed special emphasis on the role of language in meaning construction and assumed that high-order thinking such as understanding complex phenomena, problem solving, critical thinking, and reflective use of knowledge are accomplished through the help of language (Bruner, 1985). His central theoretical concept was that socially shared activities amongst learners are transformed into individual mental processes and cognitive development (John-Steiner & Mahn, 1996). This expands Piaget's view of cognitive development that 'Interpersonal social interaction of a learner with his or her peers and with the teacher is considered a key pedagogical strategy to facilitate learning.' (Gance, 2002).

During formal instruction, language is the primary form of social interaction through which a teacher explains the meaning of scientific concepts, terminologies, ideas, symbols or models to students (Linfield & Warwick, 1998). The language use influences how those aspects are connected and linked to learners' existing ideas. In chemistry education, there are many words that have specific meanings such as 'heat', 'bond', 'concentrate', 'equilibrium' and 'reduce' which differ from terminologies used in everyday language. Students tend to associate their everyday language with these scientific terms. Therefore, explaining such words calls for class discussion with the teacher and peers in order for the student to reach the process of knowledge and meaning construction.

Students will often encounter situations in which their arguments contradict others. Therefore, the teacher must monitor and guide the situation so that students can consciously reflect and examine their current ideas until the correct information is achieved. Although it is important for the teacher "to maintain a neutral stance during this session [collective discussion]" as suggested by Crowther (1997, p.5), students need to be guided to which ideas are inadequate, incomplete, or irrelevant as opposed to those that are scientific.

In a classroom setting, discussion is one of the main events to encourage active participation and engagement in learning. For example, the teacher is required to explain the subject contents and then students are required to justify and communicate their understanding of the contents they have learnt to the teacher and to their peers. As agreed by Mason (2001, p.306), "a classroom always consists of many students and the potential of 'multivoicedness' to increase understanding and learning is there." Therefore, within the social constructivist's view, construction of knowledge or meaning occurs whilst the ideas are communicated and negotiated (Driver, Guesne & Tiberghien, 1989). Caravita (2001) extended this aspect of social constructivism by saying that discussion generates not only students' understanding or elaboration of meaning, but also assists in the development of self-confidence and self-perception through exchange of ideas. Furthermore, collective discussion in science class discourse coheres with "science as the production of socially constructed knowledge" (Newton, Driver & Osborn, 1999, p. 554-555).

Other than being mediated by language, Vygotsky also believed that the construction of meaning takes place within the children's Zone of Proximal Development (ZPD). By definition, ZPD is "a distance between the actual development level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers" (Vygotsky, 1978. p.87). Therefore, instruction should be designed to provide structured support or scaffold, in which the student's existing ideas may be connected in a meaningful way by an expert to guide them in finding the solution to the problem. Students need scaffolding from the teacher or more capable peers in order to bridge the gap between their current idea and a desired idea needed to solve a problem; as such "knowledge is co-constructed by the group as the group interaction enables the emergence of an understanding whose whole is more than the sum of the individual contributions" Newton et al. (1999, p.554).

Krajcik (1994, p. 130), see Figure 3, proposed a social constructivism model where the construction of new understanding is facilitated by social interactions between students with instructors and/or with other students.

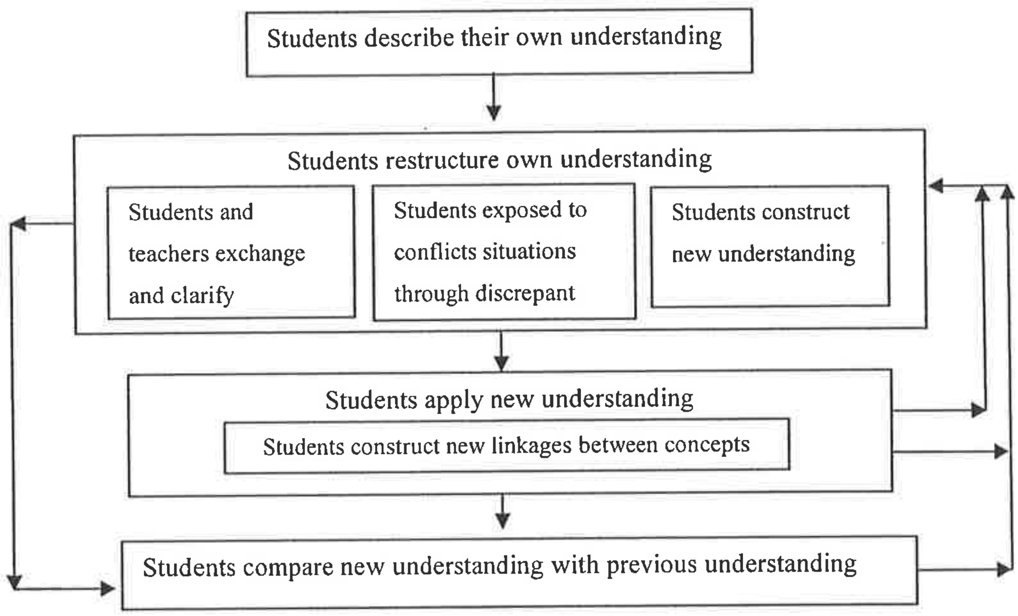


Figure 3. Social constructivism model (Krajcik, 1994, p. 130).

From the social constructivist view, students need socially rich environments to negotiate meaning and to finally convey shared understanding of a particular idea with teachers and peers. Previous studies have shown that opportunities to work with more capable peers are important to help the student develop meaning and also in their ability for solving problems.

1.0.3 Previous Studies in Cognitive and Social Constructivism

Science educators have long held an interest in cognitive and social constructivism as a theory of learning as well as a method of understanding the development of scientific reasoning in children and adolescents (Starrord, 2004). Science educators and researchers have examined how concepts are exchanged (Posner et. al, 1982), restructured (Carey, 1985), and enriched (Vosniadou, 1994) individually and socially. Science educators in particular, believe that learning science should involve an active process in searching for meaning by the learner's own construction, which results in assimilation and accommodation with existing ideas rather than direct transmission from the teacher.

In 1991, Odubunmi and Balogun conducted an investigation to study the effects of the constructivist method applied in laboratory and lecture scenarios on performance in integrated science among 210 eighth grade students from six randomly selected Nigerian schools. In this study, students who were taught using the constructivist method performed significantly better than those who were taught through the lecture method. Working in a laboratory encourages effectivel peer influence especially when group members must cooperate and discuss to complete a science experiment. The constructivist method was also found to be significantly more effective for average and low-ability students.

Scruggs and Mastropieri (1993) studied the effects of reading versus doing to increase science content knowledge amongst junior high students. Students were assigned to activity-based and text-book instructional conditions to learn science. Findings showed that students preferred the activity-based instructional condition compared to text-book instructional condition. The results suggest that constructivist-based activities, combining cognitive and social constructivist approaches when carefully structured, may facilitate the acquisition of content knowledge of even students with learning difficulties.

Similar to the work of Odubunmi and Balogun (1991), Ertepinar and Geban (1996) carried out a five-week study of the effect of instruction using the investigative-oriented laboratory approach on achievement in a science course amongst forty-three eighth grade General Science students from two classes of a secondary school in Turkey. The Logical Thinking Ability Test (LTAT) was given as a pre-test for all students to determine the intellectual abilities of all students before the treatment. The experimental group participated in five constructivist laboratory activities of 120 minutes each while the control group was taught after the classroom sessions for a total of nine hours using the worksheet method. The LTAT concluded that the subjects had identical performance related to logical thinking ability at the beginning of the treatment. The experimental group gained higher science achievement scores than those in the control group.

In a later study, a longitudinal comparison of teaching chemistry with a constructivist method (CM) was carried out by Tsaparlis and Zarotiadou (2000). Two methods were compared, namely the constructivist method (CM) and a meaningful-receptive method (MRM). Students in CM had active participation and involvement while in MRM, the teacher used advance organizers and concept maps. Results showed that the CM group scored higher in theory and generally expressed a preference for the CM in chemistry teaching as compared to MRM.

Many studies apply the cooperative learning theory, incorporating the idea of cognitive and social constructivism, that the best learning occurs when students are actively engaged in the learning process and working in collaboration with other peers to achieve a shared goal. For example, D. W. Johnson, R.T Johnson and Taylor (1993) studied the impact of cooperative and individualistic learning on high-ability students' achievement, self-esteem, and social acceptance among high-ability fourth grade students. In the study, thirty-four students were divided into cooperative or individualistic learning conditions. Under a cooperative learning condition, every student works in a group while individualistic learning is characterized as working independently towards an individualized goal. The findings show high-ability students in cooperative environments not only demonstrated higher level reasoning compared to those in individualistic learning conditions but also demonstrated higher self-esteem and academic attitude. An important concept for social constructivists here is that of scaffolding, which is a process of guiding individual learners to perform tasks that would normally be slightly beyond their ability. Scaffolding is therefore an important characteristic of constructivist learning.

Marbach-Ad, Seal and Sokolove (2001) compared a traditional instruction with student-centered instruction for teaching introductory biology to undergraduate students. The student-centered instruction involves cooperative learning and interactive engagement discussions. The findings showed that biology students favoured cooperative learning and interactive engagement discussions compared to traditional lecture instruction.

1.1 Important Aspects of Conceptual Change

This section will discuss the important aspects of conceptual change based on the nature of students' existing ideas and the conditions for conceptual change to take place.

1.1.1 Science Concepts

To understand conceptual change and its relation to knowledge construction in science education, one should first understand the meaning of a science concept and why some of the concepts are difficult to understand. As stated explicitly by Novak, Mintzes and Wandersee (2000, p. 2), "Concepts [in science] are perceived regularities in events or objects, or records of events or objects, designated by a label" which means that concepts of objects or events possess common categorical attributes. Novak and his team further explained that concepts are stored in the form of propositions. Propositions are simple statements about how some aspects of the universe are perceived (such as 'A dog is an animal' and 'Cars have four wheels') or function ('Metals are electrical conductors' and 'Anode is an electrode at which oxidation occurs'). Here, it is easier to recognize 'dog' as compared to 'conductor' due to the abstractness of the latter.

Chi (2001, 2003); Chi and Roscoe (2002); and Chi and Hausmann (2003) viewed the definition of 'concept' from an ontological perspective. They described three basic ontological categories: entities, processes and mental states. Each category has its own properties, which encompass the behaviour of members under a specific category. In science education, oxygen is an entity, which has ontological attributes such as mass and occupied space. Electrolysis is an example of a process, which has the ontological attribute of occurring over time. The concept of electrolysis as compared to oxygen is more difficult because of its abstract and dynamic nature.

Concepts in science education are connected to represent scientific theories in cognitive structure (Lawson, Alkhoury, Russell, Clark & Falconer, 2000). For example, one or more concepts can be combined to form sentences, statements or prepositions. In chemistry, 'matter consists of small particles called atoms' and 'a combination of bonded atoms is called a molecule' are considered two fundamental concepts of matter. Concepts are meaningless without complete sentences, statements or preposition. Novak, Mintzes and Wandersee (2000, p. 3) further stated that in science education "all knowledge is constructed from concepts and relationships between concepts."

Why should understanding concepts be so difficult for some students? Chi, Slotta and deLeeuw (1994) used epistemology in relation to the nature of entities to explain why students find it difficult to understand some concepts. This happens when they try to solve problems using concepts which belong to different ontological categories. The authors also discovered that some students experienced misconceptions because they assigned a science concept to an inappropriate ontological category. For example, students tend to interpret heat as having mass and occupying space. This misunderstanding on the ontological level leads to predictive errors such as mixing a cup of water at 25°C with another cup of water at 25°C results in a final temperature of 50°C. The addition of heat is an erroneous transfer of the mass addition idea that they already possess.

Since learning involves the construction of knowledge, students' existing ideas must be taken into consideration when teaching new concepts. In reality, students enter the classroom with some ideas about the concepts to be taught. Most students, especially at secondary and post secondary level, know something about any topic to be learnt in the form of ideas, knowledge, facts, information or experiences that they hold or had constructed during their earlier formal science instruction (Windschitl & Andre, 1998) as well as from everyday conceptions (Nieswandt, 2001). Therefore, as mentioned by Vosniadou (2001):

> ...information is consistent with prior knowledge, it can be incorporated easily into existing conceptual structures. This type of information is most likely to be understood even if it is presented as a fact without further explication. However, when the new information runs contrary to existing conceptual structures, simply presenting the new information as a fact may not be adequate. (p. 393)

According to Chi and Roscoe (2002), students' existing ideas are often incorrect and incomplete when compared to scientific concepts. In chemistry education, Sanger and Greenbowe (1997a, 1999), conducted two interesting studies in electrochemistry based on the assumption that undergraduate students enter the classroom with some incorrect existing ideas or misconceptions. In these studies, they pointed out thirty-two common student misconceptions of the electrochemical cell. Most of the students failed to identify some concepts such as electron flow, the function of the salt bridge, the oxidation-reduction half-reaction, cation movement, and electrolysis product. Many students also failed to identify non-observable phenomena such as the movement of electrons and ions in conducting electrical current. In many cases, students perceived both electron and ions as similar entities. Table 2 lists 12 of the commons misconceptions in regards to electrolytic and galvanic cells (Sanger & Greenbowe, 1999).

Table 2

Student Misconceptions in Electrochemistry

Electrolytic Cell
▪ No reaction will occur if inert electrodes are used. ▪ Oxidation occurs at the cathode and reduction occurs at the anode. ▪ In electrolytic cells with identical electrodes connected to the battery, the same reactions will occur at both electrodes. ▪ Water is unreactive toward oxidation and reduction. ▪ When predicting an electrolytic reaction, the half-cell reactions are reversed before combining them. ▪ Inert electrodes can be oxidized or reduced.
Galvanic Cell
▪ Electrons enter the solution from the cathode, travel through the solutions and the salt bridge, and emerge at the anode to complete the circuit. ▪ Anions in the salt bridge and the electrolyte transfer electrons from the cathode to the anode. ▪ Electrons can flow through aqueous solutions without assistance from the ions. ▪ Only negatively charged ions constitute a flow of current in the electrolyte and the salt bridge. ▪ The anode is negatively charged and releases electrons; the cathode is positively charged and attracts electrons. ▪ The anode is positively charged because it has lost electrons; the cathode is negatively charged because it has gained electrons.

Misconceptions of any scientific concepts amongst students are crucial as they would influence their future understanding of more advanced concepts. Some of these misconceptions can easily be revised or restructured, but some are highly resistant to change especially if they provide satisfactory interpretations to the students (Tao & Gunstone, 1999; Swaak, 2001). Although some of the students' existing ideas contradict scientific ideas, they often find that their ideas are more meaningful compared to the scientific ideas because their ideas were constructed from their own observations and experiences. For example, students observe that most of the cutting tools such as knife, axe and saw-chain are made of iron, thus logically they believe that iron is harder than diamond. For them, a diamond is just a transparent precious stone used in making rings. Thus, it is difficult to change students' existing ideas by just presenting correct facts, as widely practiced in conventional or traditional instructions.

As mentioned earlier, traditional teaching approaches chiefly involve students listening to the teacher's explanations in the classroom or in the laboratory (Fosnot, 1996). On the other hand, the constructivist approaches as described by Driscoll (2000, p.376) "rest on the assumption that knowledge is constructed by learners as they attempt to make sense of their experience." This implies that a constructivist teacher should create activities that provide opportunities for the students to reflect on their own ideas while explaining the concept, event or phenomenon or while listening to others.

1.1.2 Students' Existing Ideas

One of the important elements in the implementation of a conceptual change model is the strategy to identify students' existing ideas by creating cognitive conflict situations. This is the situation where students' existing ideas are challenged "by purposefully exposing them to situations in which their predictions based on these ideas are likely to be incorrect (often using discrepant events), followed by a discussion in which they reevaluate their ideas" (Tytler, 2002, p. 31). Through discrepant events, the teacher will be able to diagnose students' existing ideas about targeted concepts (Niaz, 1995). As stressed by Clark and Jorde (2004, p.4) "the exploration of discrepant events has been shown effective in supporting conceptual reorganization." At the beginning of an electrochemistry lesson for example, the teacher may present a discrepant event by showing an electrical circuit made of two electrodes connected to a low power bulb, inserted into a lemon. The teacher can induce a discrepant event by asking "Does the lamp light up and why?" Apart from challenging student's existing ideas, such discrepant events can also stimulate students' curiosity to know and thus, motivate them to find out the answer.

After experiencing a discrepant event, students usually become dissatisfied with their own conceptions and feel the need to reorganize, restructure or change to some extent their existing ideas. Dissatisfaction in the students' mind occurs when their existing ideas are irreconcilable with the new knowledge. If students are allowed to make predictions of the outcome of specific science phenomena and then give some basic explanation of what they observe, they will be aware of any conflict between their earlier prediction and observation. Then, students must be guided to reach a plausible explanation in order to reconcile any misconception or cognitive conflict.

The phenomenon of cognitive conflict has become one of the main strategies used to promote conceptual change in teaching and learning science. For Tytler (2002, p.30) "encouraging cognitive conflict through discrepant events becomes a major strategy" in teaching for conceptual change. Lee et al. (2003) suggested that the success of students' conceptual change starts with the reorganization of existing ideas during a cognitive conflict. They further stated that it could be possible for the students to just ignore their misconceptions and cognitive conflict situation. Similarly in learning science, Chinn and Brewer (1998) listed three possible responses given by students following a cognitive conflict. These are ignoring, excluding and denying new information. As stressed by Limon (2001), students often fail to reach the stage of meaningful cognitive conflict because they did not have a relevant prior knowledge to grasp the gist of the conflict. Therefore, without the teacher's intervention in helping students to reconcile any misconceptions during a cognitive conflict situation, students generally try to escape the situation by rote learning

From the above discussion, a potential cognitive conflict seems to be an initial state of conceptual change. However, one may argue that it is not an easy task to precisely direct teachers in how to induce cognitive conflict in such a way that it would lead to conceptual change. Limon (2001) for example, commented that the cognitive conflict must first be meaningful to students, generated by the students' motivation, curiosity to know, and adequate reasoning abilities. Thus, it is crucial for science educators to be aware of students' existing ideas and develop appropriate teaching strategies in order to overcome conflicts in promoting conceptual change.

1.1.3 Conditions for Conceptual Change

One of the established conceptual change models was developed by Posner, Strike, Hewson and Gertzog in 1982. They proposed that students must first be unsatisfied with their current ideas in some way. Teaching for conceptual change must then provide intelligible, plausible and fruitful scientific conceptions. This model primarily highlights the process of accommodation and assimilation in the modification of existing ideas. In explaining the conceptual change from this perspective, Posner et al. (1982, p. 212) used Piaget's term of assimilation as "the use of existing concepts to deal with new phenomena" and the term accommodation to explain "if the student's existing concepts are inadequate to grasp some new phenomena successfully....then the student must replace or organize his central concepts (own conceptions)."

Therefore, teaching for conceptual change demands a teaching strategy which promotes a learning environment in which students are actively engaged in an acquisition of new knowledge. Teaching for conceptual change substantially provides this opportunity. Teachers, who effectively implement the conceptual change approach, provide opportunities for students to modify their existing cognitive structures. Such a model of teaching acknowledges a constructivist approach, precisely how Piaget viewed the process or learning. In such a situation, the instructional approach that promotes conceptual change must take into account the students' existing ideas in order to provide opportunities for the students to restructure their ideas in a context accepted by scientists.

Later researchers such as Chi et al. (1994) and Vosniadou and Brewer (1992) extended the conceptual change model by proposing two levels of knowledge restructuring from the view of learners' conceptual ecology. The most basic level involves the **addition** of new knowledge without the involvement, changing, linking or interaction of existing concepts. This simple addition of information can be considered rote learning if the information is purely memorized without understanding. Let's consider the concept of 'an acid tastes sour'. The new idea that 'lemon juice must be acid because it tastes sour' can be easily assimilated with the existing idea that 'an acid tastes sour'. This process of assimilation is described as a **weak conceptual change** because it usually involves the addition of a specific concept without changing or restructuring the overall pattern of existing knowledge.

The second level involves the **revision** of concepts which involves the process of accommodation. The process of accommodation is described as a **strong conceptual change** and usually involves the revision or restructuring of the existing idea. For example, students' understanding of 'only things made of metal are a good conductor of electricity' can be revised through instruction to a new concept that 'metals or non-metals (such as carbon) are good conductors of electricity if they allow the movement of electrons.' In this sense, the specific concept that only metals can conduct electrical current is completely revised by the new concept that the electrical conductivity is due to the movement of electrons.

From the ontological perspective as employed by Chi et al. (1994) and Chi and Roscoe (2000), conceptual change is considered easy when the initial concept and the new concept belong to the same category, or are ontologically compatible. For example, 'an atom releases electrons to form an ion' can be easily changed to 'an ion accepts electrons to form an atom' because both belong to the same category. If the initial concept and the new concept are ontologically different, conceptual change is harder. For example, the understanding that 'cathode is an electrode' (initial concrete concept) and 'cathode is where the process of reduction occurs' (new abstract concept) needs rearrangement of the ontology category.

In the early 1980's, Posner, Strike, Hewson and Gertzog (1982), a group of science education researchers and science philosophers at Cornell University, developed a theory of conceptual change based on Piaget's notions of assimilation, disequilibration and accommodation. Posner et al.'s (1982) conceptual change model includes conceptual ecology which comprises existing ideas, relationships among various concepts, new knowledge about alternative conceptions and epistemological beliefs. Moreover, from the social constructivist view, teaching for conceptual change also encourages discussion among students and teacher as a means of promoting conceptual change; thus, widely accepted in science education studies as a comprehensive conceptual change model (Duit, 1995).

The model proposes that in order to change the learners' existing ideas, they must first become dissatisfied with their prior ideas. In making a decision about the appropriate teaching strategies to promote conceptual change, Posner et al. (1982, p. 214) established four necessary conditions of instructional strategy for conceptual change to take place in learning:

1. The learner must become **dissatisfied** with his/her current idea. The learner is likely to accept new ideas if he/she is unsatisfied with his/her current idea.

2. The alternative idea must be **intelligible** or understandable and make sense to the learner. The learner understands what is being taught and is able to describe it in his/her own words. The concept 'metal is heavier than non-metal' is intelligible because it makes sense compared to 'cats eat metal'.
3. The alternative idea must be **plausible** or appear reasonable as well as believable to be applied and able to solve a specific problem. If the concept is believable, it must be able to reconcile with other accepted concepts by the learner. The sentence 'electrons move through a salt bridge to complete an electrical circuit' seems intelligible (electrons can move) but not plausible (many students think that the salt bridge conducts electrons, instead of ions to complete the circuit).
4. The alternative idea must be **fruitful** or practical and useful to solve problems in a variety of new situations or must suggest new ideas in order for the learner to accept and value it. The concept that metals are good conductors of heat is intelligible and plausible and its fruitfulness in daily life is enormous.

Posner et al. (1982) stated that the above conditions (dissatisfaction, intelligible, plausible and fruitful) determine the status of an idea held by a student. An alternative idea has a high status if it is intelligible, plausible and fruitful. A student's commitment to accept or to reject an alternative idea depends on the relative status of his/her own idea and that of the alternative. To accept the alternative idea, the student must first become dissatisfied with his/her existing ideas due to the condition that his/her existing ideas are not adequate to make sense of the situation or solve a problem.

In other words, the alternative idea must have a lower status until the student becomes dissatisfied (Hewson, 1996). Without dissatisfaction, the student will not realize that his/her existing ideas must be changed or restructured. This is because the discrepancies experienced by the student between his/her existing and new ideas are crucial for conceptual change to occur (Strike & Posner, 1992). The student will experience conceptual change if the status of new idea is high in terms of intelligibility (able to describe it in their own words), plausibility (believing to be true) and fruitful (useful to solve problems) compared to the existing idea. The student will accept the new idea when the status of this idea is significantly higher than that of his/her existing idea.

1.1.4 Level of Education

It is useful to consider the following question 'Does level of education influence the effectiveness of conceptual change approach in science learning?' Various studies on conceptual change have been conducted at primary, secondary and higher education levels. At the primary level, Diakidoy and Kendeou, (2001) conducted a conceptual change study amongst fifth grade students about day and night phenomena, which revealed that instruction using explanation had a stronger positive effect on students' conceptual change than textbook-based instruction. Meanwhile, Mazens and Lautrey (2003) conducted a study about sound amongst first to fourth grade students and revealed that conceptual change did not occur radically, but rather in terms of a gradual process of belief revision. A study conducted by Duit, Roth, Komorek and Wilber (2001) illustrated the benefits of using analogy in promoting conceptual change amongst tenth grade students. In another study, Tao and Gunstone (1999) found that tenth grade 10 students' conceptual changes were context dependent and unstable.

At the secondary level, a study conducted by Cakir, Yuruk and Geban (2001) provided evidence that grade eleven students who were exposed to conceptual change text-oriented instruction had a better understanding of cellular respiration concepts than those exposed to traditional instruction. In another study, Eryilmaz (2002) found that conceptual discussion amongst high school students was significantly effective in improving students' understanding of force and motion. Meanwhile, a study by Ogunsola, Merfy and Comfort (1998) revealed a more positive attitude towards learning biology amongst secondary school students who were exposed to conceptual change teaching strategies than those exposed to the traditional method.

At the higher education level, Niaz, Aguilera, Maza and Liendo (2000) conducted a study on first-year students enrolled in a University chemistry course. The findings showed that an experimental group who actively participated in collective discussion experienced better conceptual change than students in a control group. Cassata, Himangshu and Iuli (2004) conducted a five-year study using concept mapping to assess undergraduate student's conceptual change as a result of attending a science course. Concept maps were developed from student interviews and used to measure change in conceptual understanding in comparison to a baseline map generated from a faculty interview. Findings revealed a gradual increase of conceptual understanding among students.

In summary, these findings indicate that the conceptual change strategies are applicable across all ages and all educational levels. Generally, most of the research has resulted in demonstrated positive effects. These findings provide a strong foundation to explore the targeted use of computer technologies to enhance students' conceptual change.

1.2 Computers in Science Education

According to Ainley, Banks and Fleming (2002), computers in science education can generally be categorized into (a) information resource tools, and (b) knowledge construction tools. As information resource tools, computers are used to retrieve information from educational courseware or through the Internet. An example of an information resource courseware is Chemistry Set 2000, published by New Media Press Limited (1998), United Kingdom. Students or teachers often use such courseware to access extra information about subject contents. In the second category, computers act as knowledge construction tools often emphasizing practice and drilling of materials. An example of a reinforcement courseware is ChemTutor, published by Interactive Learning Incorporated (2000), United States. This type of educational courseware typically contains terminology-definition-example sequences of facts, followed by a quiz-answer section. Most coursewares have features such as buttons, text, graphics, video clips and sound, which make revision easier and quicker. As stated by Dimock (2001, p. 2), the use of such courseware "mirrors traditional classroom practice: users are relatively passive, the content and interaction between the user and software are predetermined."

Alternative categorization of courseware is provided by Mayer (2005) who divided courseware for learning into Primary Courseware (PC) and Desktop Courseware (DC). PC, such as Chemistry Set 2000 is usually produced professionally, authored by subject matter experts but designed and programmed by specialists as a commercial product. DC is usually constructed by teachers or lecturers for their own students and courses. Reid, Zhang and Chen (2003) argued that any learning courseware, whether PC or DC, should be designed for understanding and not just an alternative tool of presentation.

As stressed by Kennedy and McNaught (1996), most of the educational courseware is self-paced multimedia package, which relies on students working alone without the teacher's intervention. The authors added that working alone without the teacher's intervention is not a good approach. Interaction and discussion with the teacher is necessary for the construction of knowledge to take place before it can be conceptualized individually.

Perhaps one of the earliest impacts of computers in education are the data projectors gradually replacing overhead transparencies which enable teachers to insert multimedia features such as digital images, video clips and audio, in a PowerPoint presentation. However, as argued by Bartsch and Cobern (2003), this type of digital presentation is not effective when the material presented include non-text items such as pictures and sound effect. The authors compared the preference of undergraduate students of three types of PowerPoint presentations in lectures: presentation with text, presentation with text and relevant pictures, and presentation with text and pictures that were not relevant.

The findings showed that of the three, students had the least preference for the third type of presentation. These studies thus show that the way the content is presented plays an important role on the effectiveness of the presentation. They argue that even though PowerPoint or any computer presentation can be beneficial, material which is not relevant to the subject matter should be avoided.

Lately, the increasing availability of advanced developer-friendly authoring software has enabled the use of computers as an alternative constructivist medium for teaching and learning science. Researchers have claimed that constructivist computer-based instruction can promote a discovery environment (de Jong, Joolingen, Swaak, Veermens, Limbach, King & Gureghian, 1998; Reid, Zhang & Chen, 2003), support a collaborative learning environment (Milrad, 2002), make scientific concepts easier to understand (Ronen & Eliahu, 2000) and enhance students' conceptual change (Tao & Gunstone, 1999; Windschtil & Andre, 1998).

In relation to the implications of the latest computer technology in education, McNaught (1996, p.382) listed seven epistemological movements:

1. From object-focused to process-oriented views of knowledge;
2. From individual ownership to a community ownership of knowledge;
3. From a transmissive to a transformative view of student learning;
4. Towards collaborative processes;
5. Towards a public process of peer refereeing;
6. Towards a greater focus on associational thinking over linear thinking; and

7. Towards the use of visualizations as both research and teaching strategies.

Kennedy and McNaught (1996) called this change an epistemology shift, in which teaching is no longer solely a process of giving away information but a process where students are involved directly in the process of constructing knowledge. Finally, as stressed by Iwanski (2000):

> Computer technology in education is generally effective in allowing for better understanding of the teaching materials, facilitating interaction between students and instructor, making better use of examples and illustrations, holding attention longer, easier to comprehend and to retain information and stressing important and relevant information. (p. 44)

For this to be achieved, computer courseware should be designed to facilitate the construction of knowledge. The present study has designed this kind of computer courseware to teach the fundamentals of electrochemistry using animations particularly to systematically portray concepts at the symbolic, macroscopic and microscopic levels.

1.3 Reasons for Animation

Although the conceptual change strategy is widely described in this study, not much is known about the effectiveness of using animations to enhance students' conceptual change in chemistry education. Harrison and Treagust (2000, p. 1011) argued that there are chemical concepts that cannot be explained through concrete analogical or scale models, especially dynamic and abstract theoretical processes. They suggested the appropriateness of using integrated multiple models such as the use of animations for representing complex and dynamic concepts. According to the authors, analogical models may help students to develop their own mental models of a particular scientific phenomenon but the congruency of the students' understanding with the teachers' expectation is questionable.

On a similar line, Jimoyiannis and Komis (2001) suggested that animations are suitable to present scientific concepts because they can bridge students' existing ideas with the new information and help them develop scientific understanding through an active reformulation of their misconception. The authors then proposed that animations can be designed to display scientific phenomena and to investigate abstract, complex and technically difficult phenomena in normal education settings. However, animations in this study are constructed to display the order of events or chemical processes through step-by-step discrete sequences instead of presenting them as a single frame. This may be understood as using a simple simulation. For example, animation is used to simulate the motion of electrons and ions in electrochemical cells.

According to Kennedy and McNaught (1996), animation presentation is aligned with the constructivist view, especially when the animation is designed to provide processes in step-by-step discrete sequences. For example, animating a simple electrolytic cell allows students to visualize the movement of ions in the solution and then predict the half-equation reactions at the anode and the cathode electrode which would be impossible to do through conventional static illustrations. Moreover, presenting animations will help students develop in-depth content understanding (Edelson, 2001).

Burke et al. (1998) argued that animations have the ability to communicate abstract conceptual processes to students at a microscopic level of presentation, thus facilitating a construction of knowledge. In the process of electrolysis, students can see explicitly which electrons are donated and which element is reduced or oxidized. In addition to the ability to communicate abstract concepts, animations can anchor accurately the patterns of dynamic processes and simultaneously facilitate students' own analysis of their current understanding at every stage of the process. This is supported by Jimoyiannis and Komis (2001, p.185) who contend that computer animation "provides a bridge between students' prior knowledge and the learning of a new physical concept, helping students develop scientific understanding through an active reformulation of their misconception."

In relation to this study, the instructor's explanation (narration) and contextual questioning for discussion based on the animations serve as scaffolds which help students to concentrate on the topic of discussion in order to construct scientific explanations. Furthermore, clear explanations by the instructor, active student engagement and explicit sequences of animations are expected to promote deeper learning as well as to encourage student interest, motivation and eagerness to learn more (Iwanski, 2000).

The advantages of animations in supporting instructor's direct explanation can also be viewed briefly from an information-processing model as shown in Figure 4.

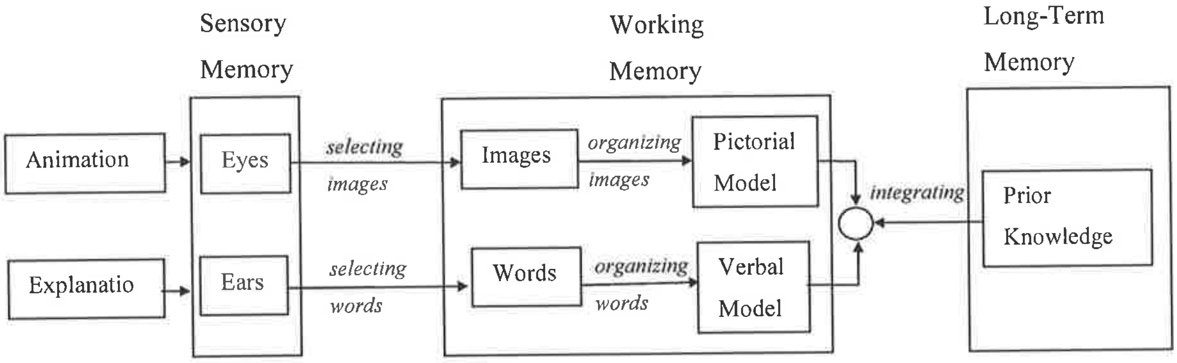


Figure 4. A framework of information-processing model for multimedia learning.

As shown in this model, the instructor's role is to attract and hold students' attention by explaining and highlighting the most important information to be understood, aided by explicitly-designed animation. Animation is one of the most significant forms of organized and attractive presentations. As sensory memory is exposed to many irrelevant stimuli during instruction (music, noise or object movement) which can distract students' attention, it is important to develop clear, straightforward systematic animations that give students a sharp focus.

According to Mayer and Moreno (2003), during computer instruction, the learner mentally organizes the selected words and images into a coherent mental representation in working memory that the author called a verbal and pictorial model. This is followed by the process of integrating the verbal and pictorial models with prior knowledge. The integration process occurs when the learner corresponds the pictorial and verbal models simultaneously in working memory. According to Mayer (2003b), the processes of selecting, organizing and integrating are important in the construction of learning outcomes, before they can be indexed in long-term memory. He added that meaningful learning and deep understanding occur when the learner mentally connects both verbal and pictorial models with appropriate knowledge from long-term memory. For instance, the animation of the salt bridge designed in this study focuses on the dynamic movement of anions, cations and electrons. The animation clearly shows only particular anions or cations moving and migrating in order to balance the electrical neutrality. The main focus of the animation is to show how ions which carry electrical charge, complete the circuit.

Mayer (2003b) claimed that based on the Paivio's dual coding and the contiguity principles, animations on the screen and live explanation from the instructor simultaneously enhance students' conceptual understanding. According to the dual coding principle, knowledge in general can be visually and verbally coded and stored effectively in long-term memory. The information interacts with new information already stored to build larger networks of concepts (Gabel, 1999). Moreover, the information coded through verbal and imagery channels in the long-term memory is much easier to retain and recall than just memorizing the information.. When referring to computer animation, Mayer (2003a, p. 319) stated that "animations enable deeper coding and more expert-like mental models of the particulate nature of matter, as compared with the static visual such as transparencies and chalkboard diagram."

The contiguity principle states that it is more effective to present corresponding words and visuals simultaneously rather than separately in presenting information. Michas and Berry (2000) stated that the contiguity principle has been found effective for students with low existing ideas because they can only generate their own mental model with the aid of pictorial and visual presentations. Therefore, it is better to present animation and live explanation from the instructor simultaneously in order to enhance students' conceptual change and deeper understanding.

In addition to dual coding and the contiguity principle, instructors should also provide scaffolds and give opportunities for students to explain and discuss their current understanding in order to encode the information within existing knowledge. This is to shift students' existing understanding to the level of a new understanding along the ZPD. One way is to use animation as a scaffold by illustrating explicit scientific process which is hard to understand just through teacher's explanation or peer discussion. A study by de Jong, Martin and Zamarro (1999) found that students' performance was improved by providing assignments with animation. In another study, Toa and Gunstone (1999) designed computer simulation programs to confront students' conceptions in mechanics. Although the result revealed positive effects, most students in the research kept changing their mind between their existing concepts and scientific concepts. Along the same line, a study by Russell, Kozma, Jones, Wykoff and Marx (1997) showed that exposure to animation instruction increased the percentage of students' correct statements and decreased the percentage of their misconceptions of gaseous equilibrium.

The literature review as mentioned above shows that computer animation has the potential to be an effective presentation tool in teaching science. As students learn better from words and pictures, on-screen animation may actively engage students in negotiating meaning in order to convey shared understanding of a particular idea.

1.4 Research Related to Electrochemistry

This section addresses research done in chemistry education, related to electrochemistry in order to understand pedagogical suggestions of effective instructions for conceptual change. Sanger and Greenbowe (1999) conducted a study by analyzing college chemistry textbooks as sources of misconceptions in understanding electrochemical cells. They analyzed ten chemistry textbooks and concluded that although these chemistry textbooks illustrate the sequence of the chemical processes, they are presented by static diagrams and were inadequate for deep understanding of the whole processes. They also suggested that the authors of the textbooks should avoid the simplifications of facts, vague statements and simple arguments in explaining the dynamic chemical processes occurring in electrochemical cells. For example, some textbooks drew the electrode anode on the left and the electrode cathode on the right throughout the textbooks. This leads to the misconception that the left electrode is always the anode and vice versa. The statement that "An electrode conducts electrons into and out of a solution" (Sanger & Greenbowe, 1999, p. 856) is an example of vague terminology written in textbooks which may lead to students believing that electrons can flow in solution.

Another study by Huddle and Margaret (2000) used what they called a concrete model for teaching electrochemistry to correct students' misconceptions in electrochemistry. This model used two boxes and polystyrene balls to represent ions in electrochemical cells. The findings of this study showed that the model did not address misconceptions but did go some way towards giving students an initial understanding of what occurs in electrochemical cells at the microscopic level.

A study by Ozkaya (2002) expanded the investigation of more complex electrochemical concepts such as half-cell potential, cell potential and electrochemical equilibrium in the galvanic cell. From the findings, he listed another nine electrochemical misconceptions that were unreported in previous studies. Again, this study's finding supported the view that students find electrochemistry difficult to comprehend because of its complex, abstract and dynamic nature.

Sanger and Greenbowe (1997b) conducted a study on specific concepts of current flow and salt bridge in an electrochemical cell to trace students' misconceptions by using computer animations. This study revealed that students who viewed the ready-made animations of electrolysis cells demonstrated fewer misconceptions. The authors suggested the use of conceptual computer animations that display dynamic motions in helping students to comprehend complex, abstract and dynamic concepts.

The same result was obtained when Sanger, Phelps and Fienhold (2000) used computer animation instructions at the macroscopic level of the process of diffusion and osmosis. As expected, the study revealed that students who were exposed to computer animations were better in answering conceptual questions. Burke et al. (1998) noted that the integration of conceptual computer animations in chemistry lessons would give better representations of the connections amongst microscopic, macroscopic and symbolic levels.

Although most of the studies mentioned above showed positive effects of animations on students' overall performances and conceptual change, a study conducted on college-level students by Sanger and Greenbowe (2000) showed otherwise. The study found no significant differences between students who viewed animations of electron flow in aqueous solutions and students who viewed static particulate drawings. The reason for the lack of effects was the way the animations were constructed at the molecular level was not much different from the static drawing. The findings suggested that some good static illustrations at the molecular level can also be visualized by students as 'crude animations.'

Therefore in teaching electrochemistry, Burke et al. (1998, p.1658) stressed that representing a chemistry event correctly is the first step towards successful teaching for conceptual change. Chiu, Chou and Lui (2002, p. 691) added that electrochemistry is difficult to comprehend not because students lack "the domain-specific knowledge"; rather, the difficulty lies in "how they construct and organize their mental models." Hence, it is suggested that chemical processes occurring in electrochemistry should be presented visually to students to give them the opportunities to visualize and comprehend the sequences of the abstract and dynamic processes. This is to avoid the common errors exhibited by students in electrochemistry problems (such as electron flow) which are related to the abstract and dynamic nature of the concepts.

1.5 Pedagogical Implications for Conceptual Change

Three key premises of the constructivist paradigm that can be used in designing conceptual change strategies for science teaching are:

1. Students construct their own knowledge, influenced by their existing ideas, in ways that may inhibit or facilitate the construction of knowledge.
2. The process of knowledge construction is an active process in which students construct knowledge and make meaning through social interactions.
3. Instead of confronting students' existing ideas, intelligible, plausible and fruitful learning materials should be presented to them.

The first premise was developed into a conceptual change model by Posner et al. (1982). As previously mentioned, based on this model, there must be conditions to be met in order for students to experience conceptual change. Therefore, one of the essential pedagogical implications is that teachers must create awareness and uncover their students' existing ideas. In order to do this, teachers should introduce discrepant events to generate moments of cognitive conflict concerning the concepts being taught as well as create awareness of the students' misconceptions (Hewson, 1992).

In the Malaysian context, students learn chemistry content through an integrated science subject for at least eight years (from primary to lower secondary) and through a specialized, chemistry subject for two years (in upper secondary). Over this time, they have constructed their own unique set of existing ideas regarding chemistry concepts in spite of exposure to the same learning opportunities in the same classroom. As a result, not all new concepts can be understood by the students in the same way.

Some of the students who have ideas that contradict standard concepts might fail to understand the new concepts correctly, especially when their erroneous existing ideas can provide some extent of explanation to some of the contradictions as previously mentioned. In the case of learning electrochemistry for example, students often associate the cathode with the negative electrode, not the process of reduction (Huddle & Margaret, 2000; Sanger & Greenbowe, 1997). This preconceived idea is perceived by the students as correct because the idea satisfactorily explains the acceptance of electrons at the cathode in the case of the electrolytic cell but not in the case of the galvanic cell. As argued by Duit and Treagust (2003) and Hewson (1992), just presenting to the students the correct specific science concepts during instruction will not necessarily result in reorganizing or replacing their misconceptions.

Therefore, it is suggested that the teacher must purposely ask questions and challenge students' answers to bring them into a state of cognitive conflict. When students fail to give correct answers, dissatisfaction occurs and alerts the students to their misconceptions. Cognitive conflict is a theory about learning which has an important pedagogical implication. For example, Nussbaum and Novick (1982) drew a teaching sequence for creating a state of cognitive conflict through the application of discrepant events. This strategy consists of four stages:

1. Identify and reveal students' existing ideas.
2. Discuss and evaluate existing ideas.
3. Create conceptual conflict.
4. Guide students to a new conceptual model.

Once students' existing ideas have been diagnosed, the teacher should present the new concept that is intelligible, plausible and fruitful in order to increase the acceptance of new ideas. For example, the concept of electrolyte must appear sufficient enough to make sense at least in explaining how an electrolyte, which consists of ionic particles, demonstrates electrical conductivity. Students should also be able to apply the concept of electrolyte in both electrolytic and galvanic cells.

The process of knowledge construction is an active process in which students construct knowledge and make meaning through social interactions. As a follow-up to the above strategies, social learning activities such as collective discussion, peer collaboration or guidance from more capable peers are important so that they can be more receptive to new ideas. These discourse activities may actively engage students in negotiating meaning in order to convey shared understanding of a particular idea, perhaps with the teacher's guidance through precise scientific terminologies and explanations, illustrations, animations, models as well as other forms of visual and symbolic expressions.

In accordance with Vygotsky's notion of the ZPD, dialogical argumentation (explication of reasoning) from collective discussion encourages students to review their existing ideas socially before they can be conceptualized individually (Newton et al., 1999). They argued that in such a manner "knowledge is co-constructed by the group as the group interaction enables the emergence of an understanding whose whole is more than the sum of the individual contributions." (p. 554). A successful discussion depends on how the teacher encourages students to participate. It is not an easy task for the teacher to ask students to give their own views on specific concepts of discussion, and why they think that is the answer. In addition, the teacher also has to encourage students to discuss the pros and cons of their answers and finally guide students towards the correct answers.

In addition to the collective discussion, the teacher should keep in mind that different students perceive things differently because not all students have the same development pattern although their age is similar. Therefore, the teacher should choose intelligible, plausible and fruitful learning materials and provide more concrete materials which cater for both the concrete and the formal operational thinkers. According to Burke et al. (1998), students have difficulty in thinking about chemical processes because most of them are oriented to concrete examples. The authors added that although students may not be cognitively developed enough to understand abstract chemical concepts, some instructional methods such as computer animation can be used to present substitute materials to the abstract concepts.

According to Burke et al. (1998), animations also provide opportunities for probing and uncovering students' existing ideas. As stated by Dimock and Boethel (2001), when students begin to interact with the animations, their active engagement and discussion provide opportunities for the teacher to explore their student's existing ideas. Furthermore, incorporating animations through a social context reflects a movement of teaching from knowledge transmission to social construction and shared meaning (Campbell, 2002).

In summary, there are general teaching principles which provide a basis for conceptual change strategies derived from the above discussion. For the implementation of these principles, science teachers must be in a position to:

1. take into consideration the importance of students' existing ideas;
2. provide intelligible-plausible-fruitful representation;
3. provide opportunities for sharing ideas and experiences;
4. encourage actively collective discussion; and
5. provide opportunities for reflective abstraction through computer animation.

1.6 Critiques of Conceptual Change

Although studies within the conceptual change framework have helped science teachers to understand the important aspects of knowledge construction, there are critiques concerning the practicality of conceptual change approach in science education. The conceptual change approach as argued by Duit and Treagust (2003) has two limitations in the broader realm of science education. Firstly, it focuses only on isolated concepts of science such as electrochemistry, heat, energy, and photosynthesis rather than the changes of overall views of the underlying concepts of the nature of science. Secondly, its approaches do not emphasize affective aspects of learning such as students' perception towards learning science and motivation. According to Lee, Kwon and Park (2003, p.587) "sometimes, affective reasons are more important than logical/cognitive reason in students' learning."

Limon (2001) has claimed that although cognitive conflict seems to be a necessary condition, it is not guaranteed that cognitive conflict will always promote conceptual change. As pointed out by Chan, Brutis and Bereiter (1997, p.2) students are "often unable to achieve meaningful conflict or to become dissatisfied with their prior conceptions." There must be strategies where students need to be aware of their dissatisfaction. Cognitive conflict conditions have also been criticized for being too subjective to be traced (Limon, 2001). Furthermore, teachers can only organize and control teaching activities but not the students' mind. In presenting teaching materials for example, what is considered intelligible and plausible by the teacher might not be considered intelligible and plausible by the students.

In relation to handling discussion or argumentation, one common problem is that some students do not readily give their opinion and participate. Even though it is good to 'learn from mistakes', most students are comfortable by just being passive spectators. In cases where students may already have rote learnt knowledge, discussion may become a mere repetition of facts.

Summary of the Literature

Constructivism from the cognitive development perspective views learners as active constructors of their own knowledge which emphasizes the importance of social contexts in learning environments. As a theory, cognitive development proposes that learning is a mental process to understand information by restructuring learner's existing cognitive structure. From this perspective, learners need scaffolding from the teacher or more capable peers in order to bridge the gap between their current idea and a desired idea needed to solve a problem. Therefore, instruction should be designed to provide structured support or scaffold, in which the students' existing ideas may be connected in a meaningful way by an expert in finding the solution to the problem.

Since learning involves the construction of knowledge, students' existing ideas must be taken into consideration when teaching new concepts. However, some of the students' existing ideas can easily be revised, but some are highly resistant to change. Studies have shown that these ideas may contradict scientific ideas, which bring misconceptions to the students. Misconceptions of any scientific concepts amongst students are crucial as they would influence their future understanding of more advanced concepts.

Based on constructivist point of view, Posner et al. (1982) developed a conceptual change model which emphasizes conditions to be met in order for students to experience conceptual change. According to this model, student must first be dissatisfied with their existing ideas. Then the teacher must present the new ideas to be taught which are plausible, intelligible and fruitful to the students.

With respect to the focus of this study, the incorporation of computer animation is believed to provide opportunities for the students to organize and comprehend the sequences of new ideas, therefore enhancing conceptual change. Computer animations also help students to link their existing ideas with the knowledge to be taught. The literature review has shown that computer animation has the potential to be an effective presentation tool as well as providing intelligible and plausible presentation in teaching science.

Such animation is aligned with the constructivist view, especially when the animation is designed to visualize scientific processes at the particulate nature of matter, thereby providing opportunities for students to gain deep understanding. Furthermore, on-screen animation may actively scaffold and engage students in negotiating meaning with peers in order to convey shared understanding of a particular concept. According to the dual coding theory, during instruction, a learner mentally arranges selected words and images into coherent mental representations which will become meaningful upon integration with prior knowledge in the long-term memory. The contiguity principle, on the other hand, states that when imparting information through animation, it is effective to present corresponding words and visuals simultaneously instead of separately. To date, there is no literature currently available in the Malaysian context that specifically addresses the conceptual change strategy by optimizing the use of systematic computer animation in science education.

Thus, although the conceptual change approach has been criticized for its narrow focus on selected scientific concepts and for ignoring affective aspects of learning, many studies have shown the positive effects of the implementation of conceptual change strategies. These studies proposed that conceptual changes strategies can be relevant across all level of education. Factors such as teacher's presentation and materials shown to the students are likely to be important in enhancing conceptual change. Therefore, in order to implement conceptual change strategies, science teachers must take into consideration the influence of students' existing ideas; provide intelligible-plausible-fruitful representation; provide opportunities for sharing ideas and experiences; encourage actively discussion; and provide scaffold to problem solving.

PART II

DEVELOPMENT OF THE COMPUTER-ANIMATED INSTRUCTION

This section discusses the development of computer-animated instruction or CAnI. In this study, CAnI is developed to integrate computer animation with constructivist chemistry instruction for use in this study. Byrne, Catrambone and Stasco (1999) defined animation as a process of moving and changing any object on the computer screen to replicate a simulation of a theoretical evolving process, event or phenomenon. Activities in CAnI are directed to promote students' awareness of their own ideas, asking for explanation of discrepant events and encouraging collective discussions.

The animations used in CAnI are originally designed by the researcher to provide intelligible, plausible, fruitful teaching materials in order to increase the acceptance of new ideas. According to conceptual change theory, once students' existing ideas have been diagnosed, the teacher should present the new concept that is intelligible, plausible and fruitful. CAnI displays straightforward systematic animations in order to manage the flow of information, to guide and scaffold collective discussion and sustain the student's focus. A copy of the CAnI courseware is attached at the inside back cover of this thesis.

2.0 Special Features

In this study, CAnI was developed using the macromedia Flash MX authoring software to animate scientific phenomena. This software provides powerful object-oriented animation features without a complex programming language.

These features are suitable for developing a clear visual animation that can facilitate students' understanding of complex, abstract and dynamic concepts at the symbolic, macroscopic and microscopic levels. It has to be noted that CAnI is a prototype model as it covers only the fundamentals of electrochemistry in general chemistry.

Macromedia Flash MX software has several special features, which are crucial in the development of computer-based instruction in teaching science. First, Flash MX has unique drawing capabilities that enable teachers to draw simple or complex diagrams related to the subject contents as shown in Figure 5. In addition to its drawing capability, Flash MX utilizes mathematically defined smooth-edge vector graphics, which require a small memory capacity.

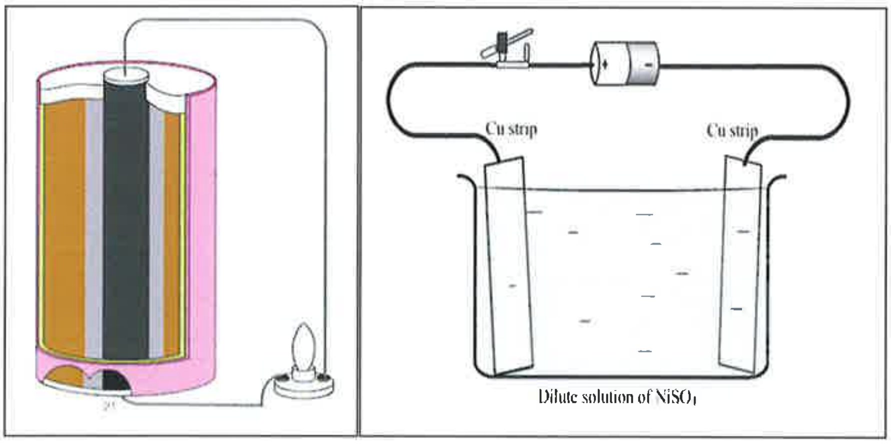


Figure 5. Diagram of dry cell (left) and electrolytic cell (right).

Second, there is also a storage facility called 'Library', which optimizes for multiple retrieval. Any graphics stored in the 'Library' can be used many times without increasing the size of the file. For example, if the diagram of a dry cell, as shown in Figure 5 appears fifty times in the lessons, Flash only stores a memory of one diagram instead of fifty diagrams.

Third, Flash uses a *tweening* (from the word 'between') approach, which creates animation between two different positions or between two different shapes. Thus, it creates animations more easily and faster than conventional frame-by-frame animations. Electron flow and metal deposition on electrode animated in CAnI are examples of motion tweening and shape tweening, respectively.

Finally, the Flash file can be saved as a stand-alone executable file. Thus, the file can be accessed through any computer operating system and can be easily up-loaded through the Internet or local networking. This feature is ideal for teamwork amongst chemistry educators.

2.1 Development of CAnI

CAnI is a prototype version of an animation-driven instructional tool. CAnI differs from most interactive educational courseware because it directly uses animations to visualize electrochemistry concepts as part of the instructional activity, rather than functioning only as supplementary material to engage with in isolation. CAnI, unlike most computer-based instruction, is designed to facilitate students to restructure their existing ideas. It consists of animations designed to represent conceptual (such as oxidation and reduction) and operational models (such as electroplating and sodium extraction) of electrochemistry concepts.

In CAnI, animations are used in conjunction with electrochemistry instruction, with the hope that students are able to visualize the connections between the symbolic, macroscopic and microscopic levels of concepts. Animations are designed as part of the instructional presentation being integrated with live explanation from the instructor. The instructor uses the conversational style (Mayer & Moreno, 2003) of explanation to highlight particular important points in the presentation. The conversational style of explanation promotes an informal conversational environment to facilitate social interaction between the teacher and other students. Consistent with constructivist beliefs, such an environment stimulates active learning and creates opportunities for students to reflect on their current understanding. Overall, the development of the CAnI final version involves six phases as outlined in Table 3.

The main purpose of the pilot studies as stated in Table 3 was to provide information on the suitability of CAnI and other instruments (pre-test, post-test, questionnaires and interview questions) used in this study. The studies were also to try out CAnI in order to minimize unexpected problems with the presentation and time allocation of each complete section of CAnI. The final version of CAnI consists of two main screens, menu and lesson screens, as shown in Figure 6.

Table 3

Development of CAnI

Phases	Actions
1. Prepare and refine lesson plan	Select main topics, learning objectives and teaching activities.
2. Prepare original draft of CAnI	Draft animations based on lesson plan.
3. First revised draft of CAnI	Original draft of CAnI was carefully evaluated by two expert panels from the Chemistry Department, University of Adelaide and one experienced Chemistry teacher from a secondary school in Malaysia.
4. Second revised draft of CAnI	The first draft of CAnI was piloted to a group of six chemistry students from University Senior College, Adelaide, followed by a group of sixteen Glenunga High International students, Adelaide, Australia.
5. Third revised draft of CAnI	The second draft of CAnI was piloted for the third time to a group of ten students from the research population who did not take part in the actual study.
6. Final version of CAnI.	The final version was used in the actual study.

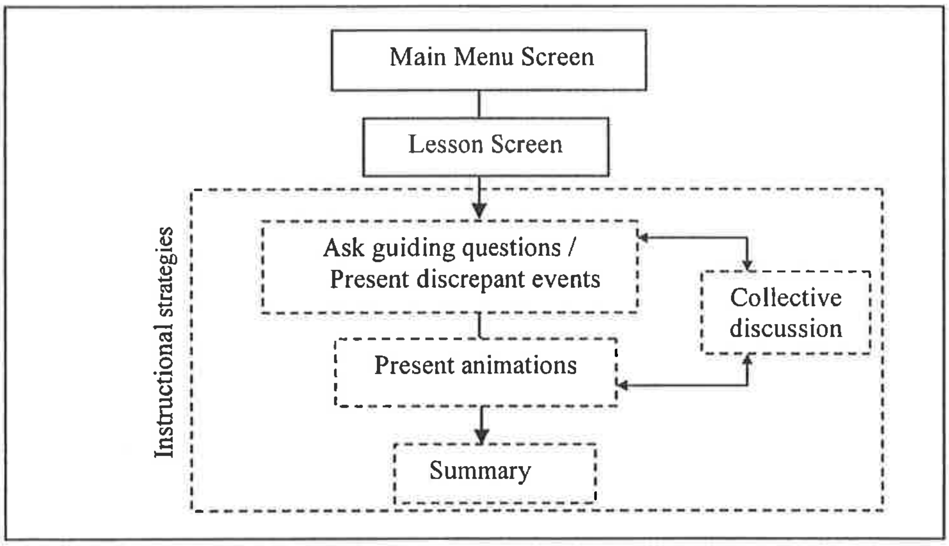


Figure 6. Organization of CAnI used in the study consists of main menu and lesson screen.

Menu Screen: The introduction screen begins with a display of the main menu. The main menu shows the main topics and subtopics covered in CAnI. The teacher can access any of the four main topics from this screen:

1. Unit 1: Introduction
2. Unit 2: Electrolytic cell
3. Unit 3: Galvanic cell
4. Unit 4: Summary

The main menu screen also shows the subtopics in every unit. For example, Unit 1: Introduction has the following subtopics:

1. 1.0 Introduction to reduction and oxidation
2. 1.1 Redox
3. 1.2 Oxidation and reduction agents
4. 1.3 Electrolyte
5. 1.4 The Electrochemical Series
6. 1.5 Electrochemical cells

Lesson Screen: The lesson screens appear either with guided questions or with a request to predict what 'physical' changes will occur. Such questions or predictions at targeted points within the animation sequence are part of the conceptual change strategy. The introduction of guided questions is one way of activating students' existing ideas and encouraging them to search for a suitable explanation. This solicits students' reflections about their current understanding.

In addition to answering questions or making predictions at the beginning of the lesson, the students are also encouraged to ask questions at any segment of the animation which needs clarification. The animation is run segment by segment using the 'Play' and 'Step back' buttons. Some of the lesson screens have an additional link to the Electrochemical Series (ES)for further references. Figures 7 and 8 are examples of the lesson screens. Note that the buttons used to control the animation delivery and the additional link to ES are highlighted in Figure 8.

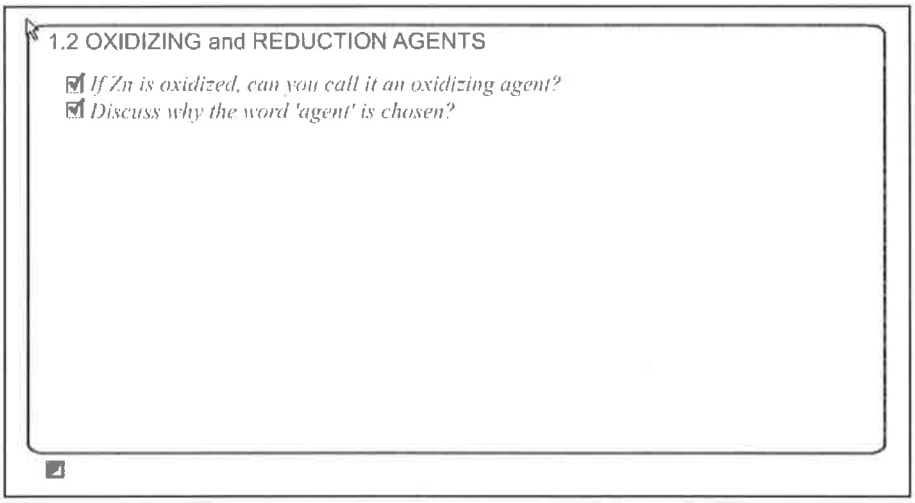


Figure7. Guided questions in the lesson screen for oxidizing and reduction agents.

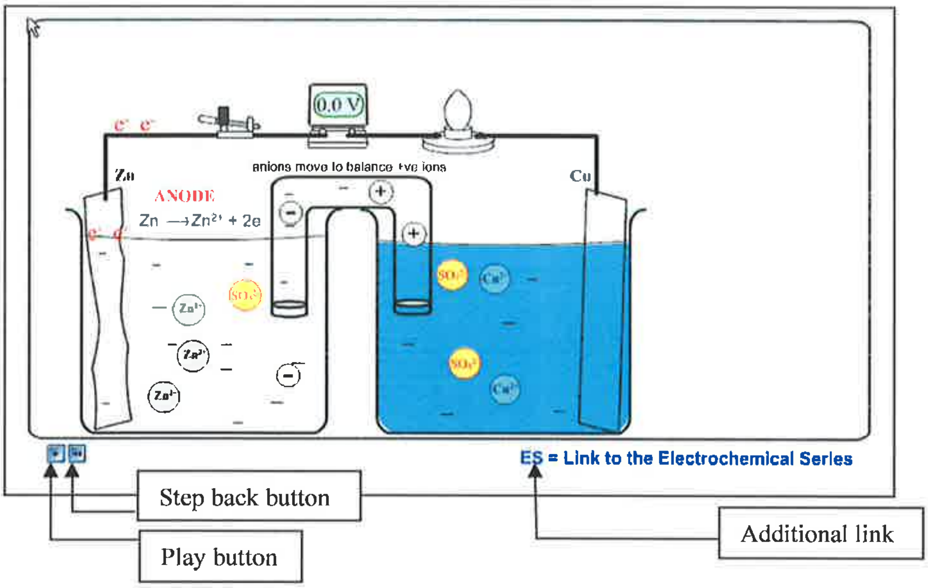


Figure8. Animation showing discrepant events in the lesson screen to diagnose students' existing ideas about targeted concepts in galvanic cell.

2.2 Orientation and Types of Animations

The animations in CAnI are designed in a discrete systematic straightforward orientation in order to maintain the students' focus on the subject contents. No sounds and unnecessary text movements, which may distract students' attention, were used in this prototype model. As stressed by Lux and Davidson (2003), a good computer-mediated instruction should avoid the use of excessive sounds and unnecessary graphics and rather emphasize a clear, direct presentation.

Apart from discrete systematic straightforward orientation, the animations are presented based on 'one-screen-one-process'. This means that only one complete process is presented in one lesson screen. The process of creating animations chiefly involves the process of organizing the movement of atoms, ions and electrons at the symbolic, macroscopic and microscopic levels. The organization of these dynamic and abstract elements provides highly focused sequence-by-sequence chemical processes. This will provide students the opportunity to directly observe simulated dynamic motion of chemical processes in the symbolic, macroscopic and microscopic levels, and so assist their understanding of complex, abstract and dynamic (CAD) concepts (Burke et al., 1998).

For instance, the animation of the silver electroplating using lead and spoon electrodes in silver nitrate solution, clearly shows electrons being release at the silver (Ag) electrode and moving to the cathode (iron spoon). Silver ions (Ag^{+}) in the solution move towards the spoon to gain electrons and plate as silver atoms on the surface of the iron spoon. The animation explicitly shows that there is no electron moving or migrating in or through the electrolyte at any time during the process. Students can clearly see the systematic process of electroplating at the molecular level.

There are two types of animations used in CAnI, these being text-based animations and process-based animations. Most of the concepts are presented by process-based animations. Both types are combined through systematic discrete sequences of a particular concept or process in electrochemistry. Examples of the text-based and process-based animations are given below.

1. Figures 9 to 11 illustrate text-based animations' snapshots.
2. Figures 12 to 14 illustrate process-based animations' snapshots.

Figures 9, 10 and 11 show the text-based animations of the redox reaction. The text-based animation consists of a 'Play' button which enables the teacher to pause or to go over a specific segment of the animation and thus has considerable control over the flow of students' discussion. This gives the teacher an opportunity to ask contextual questions at any segment of the animation which can engage the students in the learning materials. Contextual questioning and discussion derived from every segment of the explicit animation provides a link between students' prior knowledge and the learning materials. This can increase the intelligibility and plausibility of learning materials. Here, engaging students in instructional activities is important because it can generate students' interest and motivation to learn (Iwanski 2000).

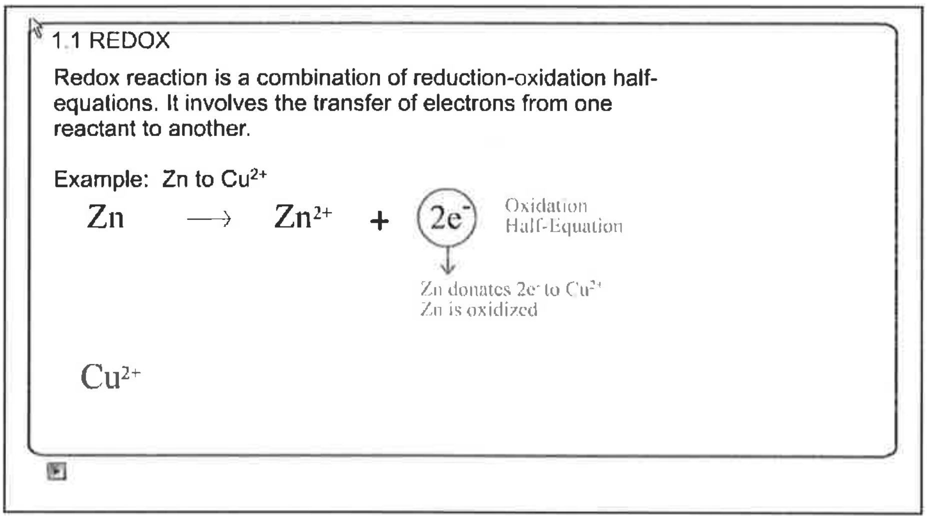


Figure 9. Snapshot 1 of redox reaction showing the transfer of electron.

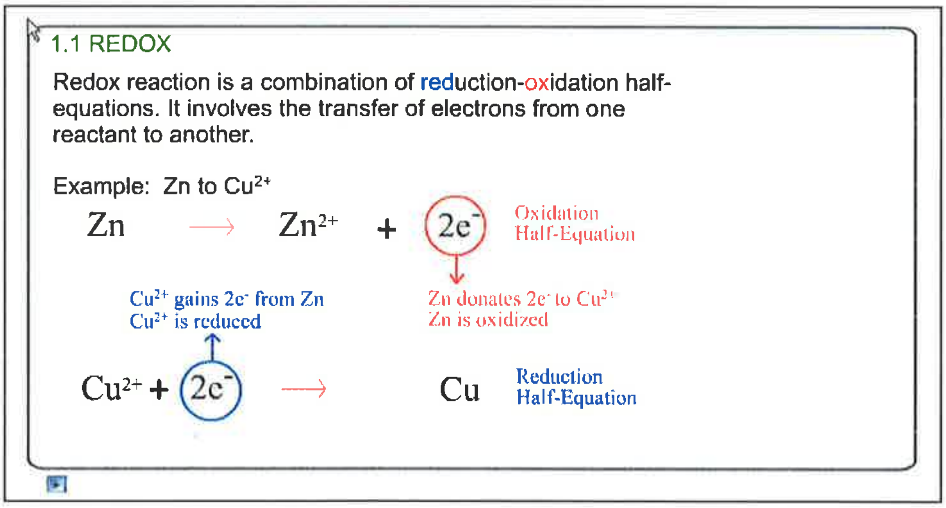


Figure 10. Snapshot 2 of redox reaction showing the combination of reduction and oxidation half-equations.

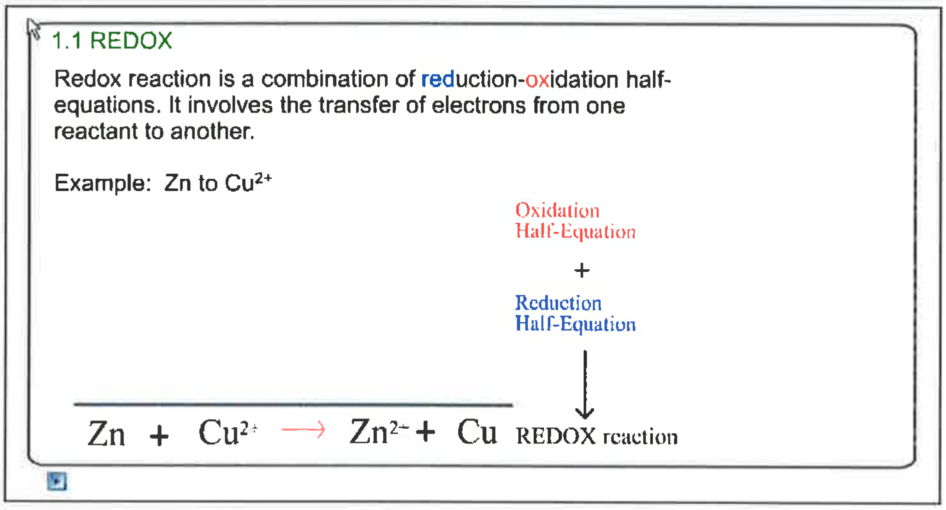


Figure 11. Snapshot 3 of redox reaction showing the addition of oxidation and reduction half-equations to construct the overall redox equation.

Figures 9, 10 and 11 above, show the text-based animations of the redox reaction in terms of electron donation and electron acceptance through simple displacement reactions. Text-based animation only displays concepts or facts at the symbolic level of presentation such as chemical equations, for example:

$$Zn + Cu^{2+} \longrightarrow Zn^{2+} + Cu$$

Figures 9 and 10 show the example of oxidation and reduction half-equations, respectively. During the process of oxidation and reduction, different colors were used to differentiate the oxidation half-equation (red) and reduction half-equation (blue). The circles and arrows emphasize the process of releasing and gaining electrons. Figure 11 shows the addition of oxidation and reduction half-equations to construct the overall redox equation.

Figures 12, 13 and 14 show the process-based animations of the silver electroplating. The process-based animation consists of a 'Play' button, a 'Step back' button and a 'Link to the Electrochemical Series'. The buttons enable the teacher to control the sequence of the animation. This gives the teacher the opportunity to ask probing questions at any segment of the animation. The 'Link to the Electrochemical Series' is an important feature which guides students to predict the species that have a greater tendency to lose or gain electrons during the process of electrolysis.

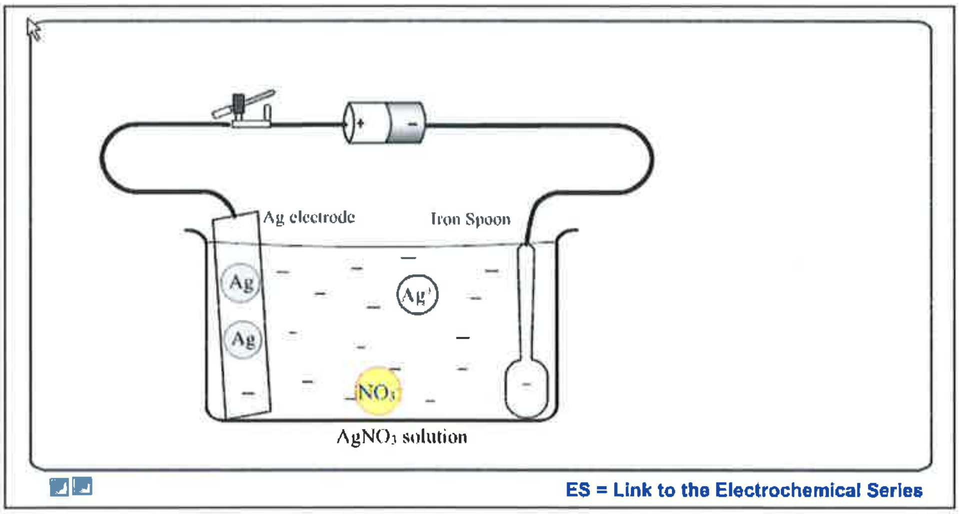


Figure 12. Snapshot 1 of silver electroplating using lead and spoon electrodes in silver nitrate solution.

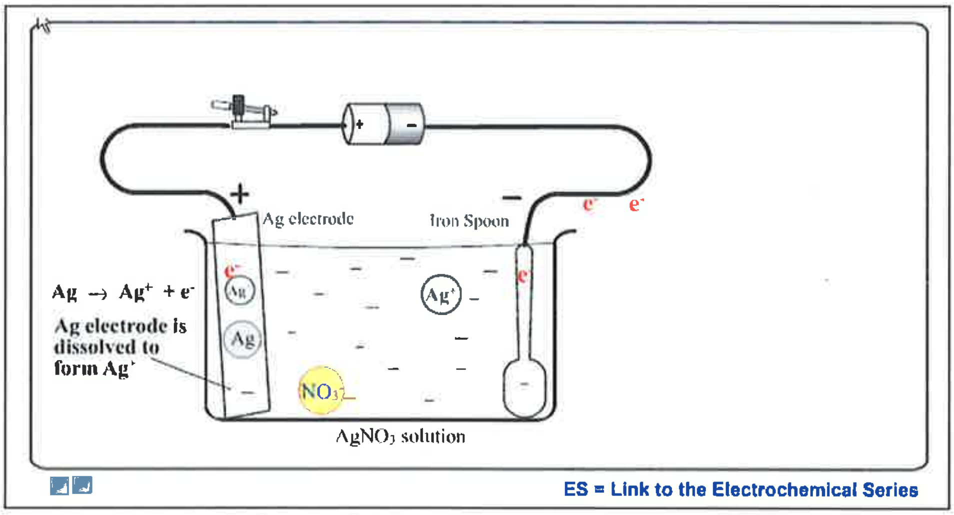


Figure 13. Snapshot 2 of silver electroplating showing the animation sequences of the electroplating processes of silver using silver nitrate solution.

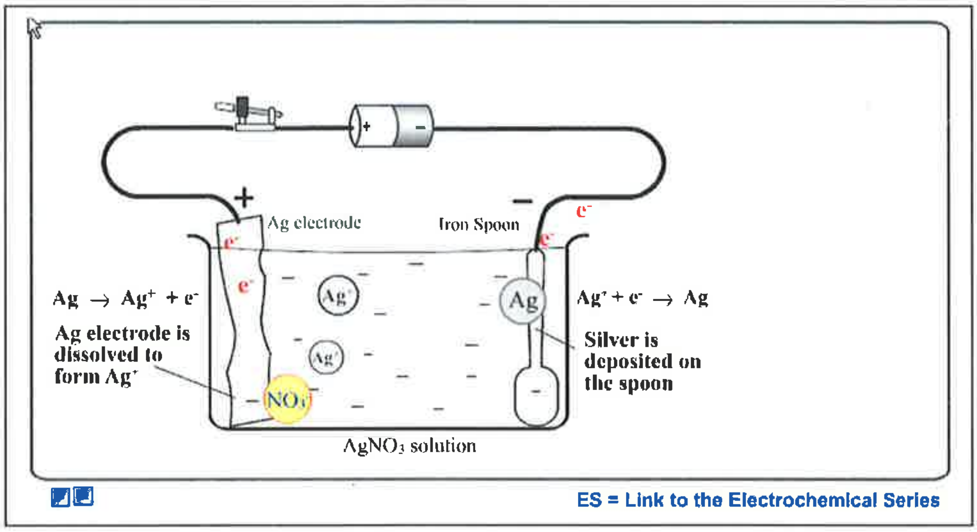


Figure 14. Snapshot 3 of silver electroplating showing the movement of the positive and negative ions to their oppositely charged electrodes.

Figures 12, 13 and 14 above show the animation sequences of the electroplating processes of silver using silver nitrate solution. A silver electrode is used as an anode electrode whilst a metal spoon is used as an object to be plated. Figure 12 shows the silver electroplating apparatus including a beaker, electrodes, ionic aqueous solution and an electrical circuit. A circular shape with chemical formula is used to represent a single ion, atom or molecule.

Figure 13 is a snapshot of the electroplating process in progress at symbolic (silver ions or Ag^+), macroscopic (changes in the anode size) and microscopic (movement of electrons) levels of animation. By clicking the 'Play' button, the switch in the animation is closed, electrons then flow to the spoon, which is then identified as the negatively charged electrode. The animation provides and clarifies the source and movement of electrons in the cell.

In Figure 14, the snapshot shows the movement of the positive and negative ions to their oppositely charged electrodes. The red circle shows the reduction process (silver received electron to form lead atom). This is an example of a reduction process in the hypothetical electrolytic cell, and matches with the definition that reduction is the process of receiving electrons. After completing the animations, which explicitly show the process of electroplating, students should be able to answer questions such as 'What is the direction of the electron flow?', 'Why does the spoon become the cathode electrode?' and 'Why is the cathode negatively charged?'.

Figure 15 shows the 'Link to the Electrochemical Series' for the process of silver electroplating. Although it is hard to predict the redox reactions with certainty, students should be able to make predictions by considering the Electrochemical Series. In Figure 15, as predicted from the Electrochemical Series, nickel ion (Ni^{2+}), a stronger oxidizing agent compared to water molecule (H_2O), is reduced at the electrode cathode of the electrolytic cell.

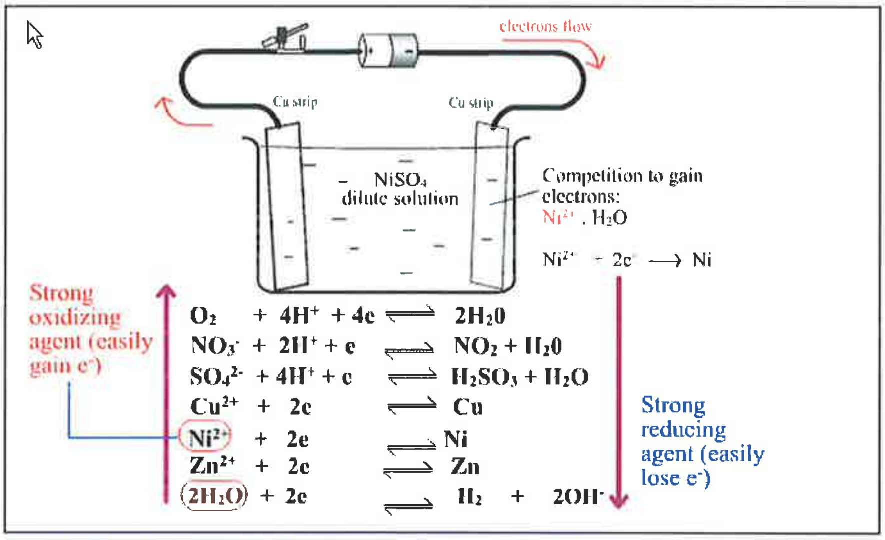


Figure 15. The Electrochemical Series.

2.3 Lesson Plan

A lesson plan is a basic requirement to guide classroom instruction to meet learning objectives and intended outcomes of the lessons. For this study, the lesson plan consists of three main sections; the main topics, learning objectives and teaching aids/activities. The learning objectives in the lesson plans are constructed based on Bloom's revised taxonomy (Anderson & Krathwohl, 2001) which combines both the cognitive process and knowledge dimensions as shown in Figure 16. The taxonomy ranges from the simplest intellectual level (remember) to the most complex (creation).

Remember

(Recalling information)

↓

Understand

(Explaining ideas or concepts)

↓

Apply

(Use information to solve new problems)

↓

Analyze

(Separate the whole of an idea into its component parts)

↓

Evaluate

(Justifying a decision or course of action)

↓

Create

(Combine elements to form something new to the individual)

Figure 16. The revised Bloom's taxonomy incorporates cognitive process.

According to Lee (2003), the six levels of Bloom's taxonomy reflect not only the importance of understanding information in its simplest form, but also the intellectual processes of application, analyzing, synthesizing, evaluating and, creating; thus including the capacity to construct knowledge. In learning science, knowledge construction begins with the simplest form when empirical evidence is transformed into facts or basic concepts. Then, through the process of inquiry, the facts or basic concepts from a student's existing ideas are transformed or changed to construct more advanced knowledge. This shows the flexibility of Bloom's taxonomy in preparing a constructivist lesson plan that fosters the process of conceptual change during the construction of knowledge.

The teaching aids/activities section was prepared based on two methods used in this study: conventional instruction and computer-animated instruction respectively. The contents in the lesson plan were developed in accordance with the chemistry curriculum of the upper secondary chemistry syllabus published by MOE, Malaysia. The lesson plan prepared for this study consists of four units: Unit 1 (Introduction); Unit 2 (Electrolytic cells); Unit 3 (Galvanic cells) and; Unit 4 (Summary) as shown in Appendix A. The contents selected for this study had been taught to all the studies subjects during their post secondary level of education.

PART III

QUANTITATIVE ANALYSIS

3.0 Introduction

The aim of this study was to quantitatively test the effectiveness of a new animation-based instructional strategy delivered in a lecture-style format. Research data was gathered to examine the effectiveness of CAnI compared to CBI in improving students' achievement of electrochemistry test scores and to explore students' perceptions towards CAnI and CBI respectively. Statistical testing was used as a major component in analyzing data obtained from pre-test, post-test and closed questionnaires.

3.1 Research Design

Research design is a plan for achieving the research objectives or answering the research questions. This study used a pre-test and post-test control group as its experimental research design, a powerful method to determine cause and effect relationship (Wiersma, 1995). The core strategy of an experimental design is to manipulate the independent variables and observe the effect on the dependent variables. This design is also known as a true experiment, as random selection and random assignment are applied in order to form two equivalent experimental and control groups to which different treatments are given.

The experimental design used in this study manipulated different instructional methods or treatments in order to determine the effect on subjects' performances, measured by post-test scores. It was designed to provide evidence that the treatment to which the subjects were exposed caused the improvement in the post-test scores. Table 4 illustrates the specific research design used in this study. Subjects were randomly assigned to two different groups; namely the CAnI group and the CBI group.

Table 4

Research Design

Group	Illustration of design						
CBI	$CBI_{(R)}$	⟶	O_1	⟶	X_1	⟶	O_2
CAnI	$CAnI_{(R)}$	⟶	O_1	⟶	X_1	⟶	O_2

Note. Abbreviations and symbols:
- $CBI_{(R)}$ indicates CBI group (as a control group) after random assignment
- $CAnI_{(R)}$ indicates CAnI group (as an experimental group) after random assignment
- X_1 represents an exposure to CBI
- X_2 represents an exposure to CAnI
- O_1 represents the process of first measurement (pre-test)
- O_2 represents the process of second measurement (post-test)
- Arrows (⟶) indicate the temporal order

The effectiveness of the treatments (X_1 and X_2) was determined by examining the differences between the pre-test and post-test mean scores for both the CAnI and CBI groups. The pre-test was administered prior to treatments whilst the post-test was administered upon completion of treatments. It was expected that the differences in means between the pre-test and the post-test scores would provide the information about the effectiveness of CAnI and CBI in terms of students' conceptual change.

According to Cook and Campbell (1979), experimental design is one of the strongest designs with respect to internal validity. They noted that "internal validity refers to approximate validity in which we infer that the relationship between two variables is causal or the absence of relationship implies the absence of cause" (Cook & Campbell, 1979, p.3). Campbell and Stanley (1963, p. 5) outlined eight main extraneous variables: history, maturation, pre-testing, measuring instruments, statistical regression, differential selection, experimental mortality and, interaction of selection "if not controlled in the experimental design, might produce effects confounded with the effects of the experimental stimulus."

Regarding interference with external validity, the authors added two external factors; experimental procedures and multiple-treatment interference. For example, the presence of observers may influence subjects to act differently from their normal behavior. Therefore, the findings of the study may be generalized only to subjects who experience similar conditions and the same sequence of treatments.

Several steps have been taken in the current study in order to control the extraneous variables. First, all of the subjects had a similar background, such as age (they were 18 to 19 years old), academic qualification (they achieved first grade in the Malaysian Certificate of Education), and ethnic background (all subjects were Malays). A random selection was employed to control statistical regression and differential selection factors. A matched random assignment of group was also used to equate the groups and balance any extraneous variables in the experiment and control groups before the treatment took place. In other words, samples were randomly allocated to treatment conditions.

The use of the CBI group as a control group, reduces the effect of history, maturation, measuring instruments, and the interaction of selection and maturation factors because both groups were exposed to the same conditions of instruction (other than treatment). Problems with maturation may be minimized if both groups are given similar pre- and post-testing. In order to minimize the variation of personalities of the instructors and wording of instruction, the same content of knowledge was implemented and the same handouts were distributed to both groups. This means that both the CAnI and CBI groups received the same diagrams, figures, and brief notes. In fact, instructors were asked to present and explain the content of subject strictly based on the lesson plans, thus minimizing the effects of their personality on the instructional effectiveness. Finally, the Hawthorne effect was minimized because the subjects involved in this study were highly self-motivated and mature college students.

3.1.1 Variables

There are two main variables in any experimental design, dependent variables and independent variables. The dependent variable used in this study was the subject's mean scores in the post-test given after treatments. The post-test questions were divided into General Questions (GQ) and Specific Questions (SQ). The independent variables were the methods of instruction (CAnI and CBI) and students' level of achievement (high and low achiever).

3.1.2 Research Hypotheses

The general hypothesis of this study was that subjects who were exposed to CAnI showed stronger conceptual change of the relevant electrochemistry concepts than subjects who were exposed to CBI. The expanded list of null hypotheses is as follows:

Ho_1: There is no difference between the pre-test and post-test mean scores of the students in the CAnI group

Ho_2: There is no difference between the pre-test and post-test mean scores of the students in the CBI group.

Ho_3: There is no difference between the post-test mean scores of students in the CAnI and CBI groups.

Ho_4: There is no interaction effect of instructional methods and students' level of achievement in relation to the post-test mean score.

Ho_5: There is no difference between the post-test mean scores for general questions of the students in the CAnI and CBI groups.

Ho_6: There is no interaction effect of instructional methods and students' level of achievements in relation to the mean score in the post-test general questions.

Ho_7: There is no difference between the post-test mean scores for specific questions of the students in the CAnI and CBI groups.

Ho_8: There is no interaction effect of instructional methods and students' level of achievement in relation to mean scores in the post-test specific questions.

Ho_9: There is no difference between the post-test mean scores of the high achiever students in the CAnI and CBI groups.

Ho_{10}: There is no difference between the post-test mean scores of the low achiever students in the CAnI and CBI groups.

Ho_{11}: There is no difference between the post-test mean scores for general questions of the high achiever students in the CAnI and CBI groups.

Ho_{12}: There is no difference between the post-test mean scores for general questions of the low achiever students in the CAnI and CBI groups.

Ho_{13}: There is no difference between the post-test mean scores for specific questions of the high achiever students in the CAnI and CBI groups.

Ho_{14}: There is no difference between the post-test mean scores for specific questions of the low achiever students in the CAnI and CBI groups.

3.1.3 Sampling Method

The research population of the study comprised first-semester science matriculation students at the Matriculation Centre, International Islamic University (IIU), Malaysia. The students had been successful in the *Sijil*

Pelajaran Malaysia, SPM (Malaysian Certificate of Education) examination. Their average age was 18 to 19 years old. All of them had acquired their knowledge in chemistry primarily through secondary education.

The Matriculation Centre, IIU was established in 1985, as one of the centers that prepares SPM holders prior to enrolling in degree programs. The Matriculation Centre, IIU was selected because of its willingness to grant permission and to give full cooperation in carrying out the study. Furthermore, the centre uses English as a medium of instruction. Chemistry is taught as one of the core subjects for science students besides Mathematics, Physics and Biology. Chemistry was taught as a four-credit-hour (five contact hours) subject and a one credit hour (three contact hours) laboratory. Overall, the students have an intensive eight contact hours per week for Chemistry.

A simple random selection and random assignment strategies were used in the current study. A simple random selection was used in selecting the subjects so that each student had an equal chance of being selected. A random assignment was used as a process to form two groups, in which the selection of one subject is independent to the selection of another subject (Burns, 1998). The aim of the random selection and random assignment was to make sure that both the CAnI and CBI groups were truly comparable and that the differences in the outcomes that were observed were not the result of extraneous variables.

The word 'subjects' is used to represent the participants involved in the study. One hundred and twenty first-semester science matriculation students were chosen from a potential research population of 250. The subjects consisted of

60 high achiever students and 60 low achiever students. This categorization was made based on the SPM Chemistry grades obtained by each student. The subjects were classified into the high achiever category if their Chemistry grade was between 1 to 4 (high pass). The subjects in the low achiever category were students who obtained Chemistry grade 5 to 8 (low pass) in the same examination. No student obtained grade 9, which is considered a fail.

Each subject from each category was randomly given a number from 1 to 60. They were then assigned to form equivalent experimental and control groups through a random allocation. To do this, the subjects with odd numbers were assigned to the experimental group whilst the subjects with even numbers were assigned to the control group. Both groups consisted of a total of 60 students with 30 high and 30 low achiever students. However, only 85 students (45 and 40 students from experimental and control groups respectively) completed all sessions of the study, 63 (74%) female and only 22 (26%) male. The low number of males precluded any analysis by gender. The subjects' distribution is shown in Table 5.

Table 5

Subjects' Distribution

	Experimental Group (CAnI Group)	Control Group (CBI Group)	Total
High achiever Students	24	20	44
Low achiever Students	21	20	41
Total	45	40	85

The sample size was considered adequate for the experimental design as Wiersma (1995, p. 296) noted that "for a tightly controlled experiment…, 15 or so subjects per group, and a total of 60 or so subjects, might be adequate." Moreover, a small sample size for an experimental design was considered adequate "if the study uses additional corroborative data such as interviews" (Cohen, Manion and Marrison, 2000, p.95). In agreement, Borg and Gall (1996, p.93) stated that "experimental methodologies require a sample of no fewer than fifteen."

3.1.4 Instruments

The main objective of this study was to investigate the effectiveness of CAnI method in enhancing science students' conceptual change and to investigate students' perceptions toward constructivist instruction in comparison to conventional instruction. The first objective was measured through pre-test and post-test scores whilst the second objective was determined by the responses to closed questionnaire given to both groups. In summary, three instruments used to provide quantitative data in relation to these objectives were pre-test, post-test and closed questionnaires.

Pre-test and Post-test

The pre-test and post-test instruments were designed to evaluate students' understanding of the targeted concepts in an electrochemistry topic using short-answer and essay questions. Short-answer questions or open-ended questions require responses of one word to a few sentences. Meanwhile, essay questions need much longer answers than those of short-answer. The combination of short-answer and essay questions is effective for assessing all levels of Bloom's revised taxonomy and "provide[s] students with greater flexibility in how they can express their responses" (Cangelosi, 1982, p. 140), hence provides a clearer picture of student current understanding. Although the questions consisted of relatively short responses, they demanded the subjects' understanding of essential electrochemical concepts in terms of organizing and integrating the concepts meaningfully and comprehensively. At the same time, the essay-type questions remove the possibility of guessing the answers.

The pre-test was administered basically to identify the range of students' existing knowledge of the fundamental concepts of electrochemistry. Then the post-test was administered after the interventions of treatment in order to identify the students' conceptual changes. These concepts covered the following subtopics:

1. Oxidation and reduction
2. Electrolyte
3. The Electrochemical Series
4. Electrolyte cell
5. Galvanic or Chemical cell

A series of revisions of the pre-test and post-test questions were conducted in order to refine the items, to enhance their clarity and conceptual strength. The stages of these revisions are shown in Table 6.

Table 6

Revision Stages of the Pre-test and Post-test Questions.

	Actions	Revision and development
1st	First pre-test and post-test drafts were designed based on a refined lesson plan.	Three experts (a lecturer and two chemistry teachers) assessed the content validity of the pre-test and post-test, which consist of 10 multiple-choice questions and 4 essay-type questions.
2nd	The first draft of pre-test and post-test were piloted with a group of six chemistry students from Bradford College, Adelaide followed by a group of sixteen students of Glenunga High International, Adelaide, Australia.	The short-answer questions were reduced and the essay-type questions were added to test higher order thinking skills.
3rd	The second draft of CAnI was piloted for the third time with a group of ten students from the research population who did not take part in the actual study to check the content validity and reliability.	The items were divided into 5 questions on general electrochemical concepts and 2 questions on specific concepts of electrolytic and galvanic cells. **General questions (GQ)** refer to questions which tested only general concepts of electrochemistry. **Specific questions (SQ)** refer to questions which tested the specific electrochemical cells (electrolytic cells and galvanic cells). The final version of the pre-test and post-test was used in the actual study.

In the first stage, the multiple-choice questions were replaced with short-answer and essay questions to avoid the possibility of correctly guessing the answers. In the second series of revision and refinement, the word 'observation' in one of the essay questions concerning electrochemical processes, '*State the observations when electric current is passed through each cell*', was ambiguous. The pilot tests had shown that different students understood the word in different ways. Some of the students gave unobservable answers such as 'chemical reactions' as the result of 'observation'. Therefore, the question was revised from '*State the physical observations (for example – color change) when electrical current is passed through each cell*'.

The final post-test questions (Appendix B) used in this study consisted of seven essay-type questions, making a total of 25 points. The questions were divided into Section A: Pre-test General Questions (or Pre-test GQ) and Section B: Pre-test Specific Questions (or Pre-test SQ). Section A was worth a total of 10 points and Section B a total of 15 points. The general questions tested the general concept of electrochemistry whilst the specific questions tested specific concepts of electrolytic and galvanic cells.

The post-test questions were identical to pre-test except Question 1 and Question 3 in Section A. Question 1 in the post-test used 'Oxidation' and 'Cathode' instead of 'Reduction' and 'Anode' in the pre-test. Question 2 in the post-test used '$CuSO_4$ solution' instead of '$PbBr_2$ molten' as in the pre-test. Examples of the questions are shown in Table 7.

Table 7

Examples of Pre- and Post-test Questions.

Questions	Examples
Short-answer	Identify the reducing and oxidation agents in the following reaction: $Zn + Cu^{2+} \longrightarrow Zn^{2+} + Cu$
Essay	What allows the solution of $CuSO_4$ to conduct an electrical current?
	In a galvanic cell, is the more active (reactive) metal more likely to be the anode or the cathode? Give your explanation.

Closed Questionnaire

The closed questionnaire used in this study consisted of the 5-point Likert scales from which respondents had to choose a possible answer. The scales were: 5 for "Strongly Agree", 4 for "Agree", 3 for "Not Sure", 2 "Disagree", and 1 for "Strongly Disagree." The closed questionnaire was used to obtain students' perceptions of CAnI and CBI, respectively. There were two types of questionnaire used in the study; type 'a' and type 'b'. The type 'a' questions were applied and answered by the subjects in the CAnI group whereas the type 'b' questions were applied and answered by the subjects in the CBI group. The following questions (Question 7a and 7b) were answered by the CBI and CAnI groups respectively. Both questions were identical except the word 'animation' and 'transparencies' interchange as follows:

7a: The teacher's explanation using transparencies corrected some of my misunderstandings about electrochemical cells.

7b: The teacher's explanation using animations corrected some of my misunderstandings about electrochemical cells.

The closed questions were constructed to present five identified themes, which were aligned with the objectives of the study. These themes were used in order to identify whether CAnI and CBI were able to (a) identify respondents' misconceptions, (b) guide respondents towards new concepts, (c) provide plausible learning materials to respondents, (d) provide intelligible learning materials to respondents, and (c) provide fruitful learning materials to respondents.

Several steps were taken to avoid pitfalls when writing and preparing the questions as suggested by Cohen et al. (2000) and Burn (1998). They suggested that good items for questionnaires should be short, clear, straightforward, and avoid leading and double-barreled questions. In relation to this, the first draft of the questionnaire was piloted in order to test the items, check the time needed to answer all the items, identify any confusing items or instructions as well as to increase the validity and reliability of the questionnaire. Table 8 shows the summary of the piloting procedures.

Table 8

Summary of Piloting the Questionnaire.

Stage	Actions	Revision and development
1st	Draft questionnaire were designed based on seven themes	Two experts (a teacher in science education and one chemistry teacher) assessed the content validity of the draft, which consists of 28 closed-ended questions and four open-ended questions. The time required for completing the questionnaire ranged from 10-20 minutes.
2nd	The first draft of the questionnaire was piloted with a group of six chemistry students from Senior College, University of Adelaide.	The items were refined and reworded. The questionnaire was divided into two sets of questions (one for each method of instruction) to avoid confusion between the words 'animations' (for CAnI) and 'illustrations' (for CBI).
3rd	The second draft of the questionnaire was piloted with a group of sixteen students at Glenunga High International, Adelaide, Australia.	The second draft functioned as expected.
4th	The final version of the questionnaire, which consists of 24 items was piloted for the third time with a group of ten students from the research population who did not take part in the actual study.	Reliability of the final version is calculated as satisfactory. The questionnaire is ready to be administered in the actual study.

After piloting, only 24 items remained in the final version of the questionnaire. Questions 2, 7 and 15 represented the first theme (Identify respondents' misconceptions), which were constructed in order to find out the importance of the teacher's roles in encouraging students to actively express and discuss their ideas during classes. For example, Question 2 for the CAnI group is 'The teacher encouraged the students to actively give ideas and comments in collective discussions.'

In learning new concepts, students need guidance or scaffolding from the teacher in order to internalize the concepts of the new ideas. One of the teacher's roles is to provide organized materials, aiming to change students' existing understanding to a new understanding. Questions 3, 8, 9 and 23, represented this theme (Guide towards new concepts). For example, Question 3a for the CBI group is 'The teacher systematically introduced one concept after another using the transparencies.'

The third, fourth and fifth themes were interrelated. The third theme (Provide plausible learning materials to respondents) was concerned with how students' beliefs of a concept could be fitted with other concepts they already knew or had learnt, and was represented by Questions 4, 5, 13 and, 18. For example, Question 4 for the CAnI group is 'I think the animations shown in the class made learning electrochemical cells much easier.'

Concepts are considered intelligible if they make sense to the students. The fourth theme (Provide intelligible learning materials) was represented by

Questions 1, 16, 21, 22, and 24. For example, Question 21 for the CBI group is 'I could easily understand the logic of my teacher's explanation through the transparencies.'

Finally, the concepts can only be fruitful if they seem intelligible and plausible to the students and must be useful to solve problems in various situations and conditions. As noted by Duit and Treagust (2003, p 677) "for a concept to be fruitful, it must first be intelligible and plausible and should be seen as something useful to solve problems." Questions 6, 10, 11, and 12 represented the fifth theme (Provide fruitful learning materials). For example, Question 11 for the CAnI group is "The animations used by the teacher helped me to predict the process occurred at the anode and the cathode."

3.1.5 Validity and Reliability of Instruments

Validity refers to whether a particular instrument measures what the researcher wants it to measure (Burn, 1998). Meanwhile, the term reliability refers to the consistency of scores (Anastasia, 1998), or to the consistency of evaluation results (Gronlund, 1985). Based on these definitions, this section discusses the validity and the reliability of the pre-test and post-test essay questions and the closed questionnaire used in this study.

Pre-test and Post-test Essay Questions

According to Isaac and Micheal (1983), content validity is important for any test of learners' degree of attainment of subject matter domain. Cannon and Newble (2000, p. 168) stated that content validity "is the first priority of any assessment." The authors stressed that any assessment should represent materials taught in the lesson. They added that validity of the test could be improved by carefully matching the test with the instructional objectives. In this study, one lecturer in science education and two chemistry teachers were invited to be the panel of experts, who validated the content of the tests.

Besides strong content validity, the test should also demonstrate reliability. According to Miller, Imrie and Cox (1998), it is difficult to determine the reliability of essay questions. However, the reliability of essay questions can be improved if the marking scheme is designed according to the contents of the subject (Partington, 1994). Several procedures were carried out in order to establish the reliability and the validity of the pre-test and post-test of the study. The procedures were as follows:

1. The tests were checked and evaluated by a series of consultations with independent experts for content validity by comparing the content of the tests and the lesson plans.
2. The tests were piloted twice on a group equivalent to the research population (in terms of age and exposure to electrochemistry concepts).
3. The tests were piloted once on a group selected from the research population.
4. The tests were graded by a former experienced matriculation Chemistry teacher who is currently working as a chemistry teacher in one of the secondary schools in Malaysia. Her background in teaching Chemistry at the matriculation and secondary levels gives her an excellent understanding of electrochemical concepts.

5. In order to increase the reliability of the grading of the tests and to minimize the halo effect, the subjects' answers were graded on a 'one question at a time' basis.
6. The marking scheme was based on the content of the lesson plans.
7. A lecturer from the Universiti Kebangsaan Malaysia randomly checked the grading processes. He has had more than ten years of teaching experience at one of the matriculation colleges in Malaysia and is one of the examiners for the Examination Syndicate. He randomly took ten test papers from each CAnI and CBI groups to check the consistency of the marking process.

Closed Questionnaire

The closed questionnaire used in this study consisted of 24 items, each using a Likert scale with five response options. The reliability of the questionnaire was estimated through internal consistency reliability. Cronbach's alphas (also known as coefficient alpha) were used to estimate the internal consistency of the questionnaire. The coefficient alpha for this study was .77, demonstrating that the questionnaire had high reliability for the study (Pallant, 2001).

To establish the internal validity of the closed questionnaire, the items were constructed based on the theoretical background of conceptual change instructional strategies as discussed in the literature review. The conceptual change instructional strategies focus on modifying students' misconceptions, followed by the provision of plausible, intelligible, and fruitful materials. These theoretical backgrounds were used as themes in constructing the questionnaire questions. To establish the external validity, the questionnaire was piloted twice to a group of students with an equivalent academic background and age and finally to a group of students from the research population who did not take part in the actual study.

3.2 Procedure

The lessons for the CAnI and the CBI groups were conducted concurrently. That was the best solution given by the administrator of the Matriculation Centre, in order to avoid any clash with the formal classes. Therefore, two instructors were involved in teaching the CAnI and the CBI groups, respectively.

One of the Chemistry teachers at the Matriculation Centre, IIU, volunteered to be an instructor for the CBI group. Miss Maria (not her real name) is an experienced Chemistry teacher, who has eight years of experience in teaching Chemistry. Meanwhile, the researcher of this study himself conducted the classes for the CAnI group. A series of meetings were held between the researcher and Miss Maria in order to discuss the content of the lesson plan and the materials provided for the lessons. The main objective of the meetings was to make sure that the same subject contents, learning objectives and handouts were employed during the period of treatment so as to minimize instructor bias.

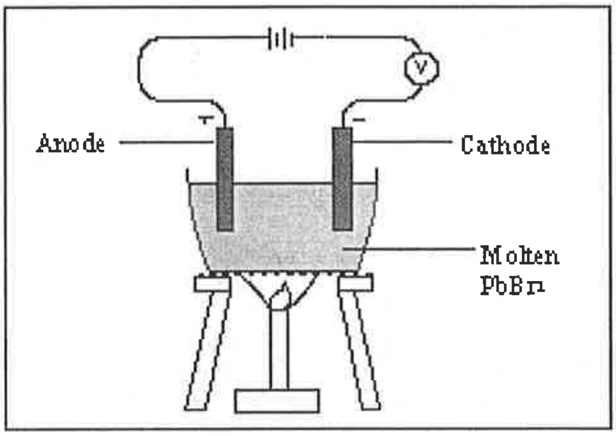
3.2.1 Materials

Figure 17 shows the example of the transparencies used by Miss Maria in her class. The transparencies provide brief information and short notes of the main concepts as well as illustrations covering the lesson plan. These transparencies were actually retrieved from the same content used to develop the animations for the CAnI group. Figure 18 shows an example of a snapshot of the content exposed to the CAnI group.

Unit 2 – Electrolytic Cell

2.1 Molten $PbBr_2$ with inert electrode

The batteries pump electrons to the negative electrode and remove electrons from the positive electrode.



At the cathode

$Pb^{2+} + 2e \rightarrow Pb$

At the anode

$2Br^{-} - 2e \rightarrow Br_2$

or $2Br^{-} \rightarrow Br_2 + 2e$

Overall balanced redox reaction:

$Pb^{2+} + 2e \longrightarrow Pb$

$2Br^{-} \longrightarrow Br_2 + 2e$

$Pb^{2+} + 2Br^{-} \longrightarrow Pb + Br_2$

Figure 17. A sample of a transparency shown to the CBI group.

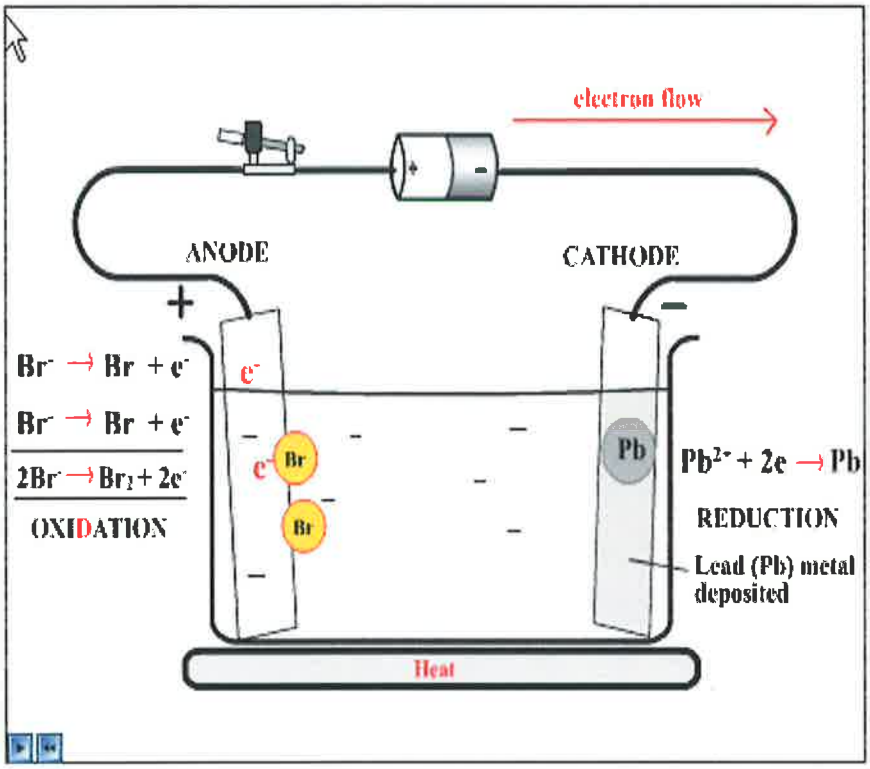


Figure 18. A snapshot from the animation shown to the CAnI group.

3.2.2 Session and Treatment Duration

The study was conducted in four sessions. In session one, the pre-test was administered to the CAnI and the CBI groups. The pre-test took 40 minutes to complete. This was followed by session two, involving four electrochemistry lessons as treatment. Each lesson was designed as a normal 50 minute lesson. Session three took place at the end of the treatment sessions. In session three, the 40 minute post-test was administered, followed by the closed questionnaire. The closed questionnaire took approximately 20 minutes to complete. Session four was the interview session, which is discussed in the next chapter.

The treatment duration of this study was four-sessions comprising 50 minutes for each lesson, which is sufficient based on the strict condition and design of the study. Kokkotas and Vlacos (1998) noted that four-sessions of treatments were adequate for testing hypotheses under a tightly controlled experimental procedure, when using mature learners and when teaching a specific domain of knowledge. According to the authors, the cognitive engagement for mature learners is believed to occur spontaneously during the treatments.

3.2.3 Treatment for Conventional Group

In teaching the CBI group, the instructor used prepared transparencies and presented the lesson in a conventional way through direct instruction approach. She started by giving an introduction to the lesson during the first few minutes of the lesson time. The next 40-50 minutes were the devoted to class activities as stated in the lesson plan. During the lesson, the students' attention was directed to the illustrations drawn on the transparencies. The lesson ended with a 15 minute question-and-answer session through a teacher-dominated discussion. During the discussion, the teacher answered all questions by students immediately. She ended the lesson with a conclusion.

3.2.4 Treatment for the CAnI group

Teaching in the CAnI group was based on computer-animated instruction, with the subject matter being presented using a laptop computer and a data projector. At the beginning of the lesson, the teacher spent a few minutes asking questions to probe the students' existing ideas. The next 40-50 minutes was devoted to the class activities as stated in the lesson plan. The lesson focused on explaining the systematic process of electrochemistry cells through computer-animated presentation. At the end of the lesson, the instructor finished with a conclusion.

3.3 Parametric Statistical Test

In this study, analysis of variance (ANOVA) and analysis of covariance (ANCOVA) were conducted to explore the impact of independent variable on dependent variable. However, ANCOVA as an extension of ANOVA, was conducted to remove the effect of the pre-test (covariate), which may influence the post-test mean scores. One-way ANOVA and ANCOVA did not specify which group was significantly different; therefore, further statistical analysis using planned comparisons was conducted. Two-way ANOVA and ANCOVA were also conducted to determine the possible interaction effects between instructional methods and students' level of achievement.

Other related statistical analyses used in this study was paired-samples t-test. Paired-samples t-test (or repeated measures) was used to examine changes in the scores of the subjects after an exposure to the treatment. The subjects were tested twice, first in the pre-test and then in the post-test. Paired-samples t-test determined the difference between the mean scores of the pre-test and the post-test of the subjects in the same group.

3.3.1 Assumptions of Parametric Statistical Test

The parametric statistical tests mentioned above required assumptions for conducting a particular hypotheses-testing procedure. Parametric tests measure an interval scale such as scores by individuals, which is normally distributed in the population. The scores are obtained from random sampling and assume variance across populations to be equal (Shavelson, 1988). There are three general assumptions that need to be considered for the parametric tests to make sure that the tests are accurate. The assumptions are normal distribution, homogeneity of variance, and independence of observations. The assumptions and the related tests are presented in Table 9:

Table 9

Assumption of Parametric Data.

Assumptions	Explanation	Test
Normal distribution	The distribution of scores for each group is normally distributed.	Shapiro-Wilk's Test
Homogeneity of variance	The variability of scores for each group is similar.	Levene's Test
Independence of observations	The scores from each group are independent.	No specific test but based on the strict procedure of experimental design.

Normal Distribution

The normality of scores for all groups involved in the study was tested using the Shapiro-Wilk tests of normality as shown in Appendix C. The table in

Appendix C shows all Shapiro-Wilk's tests are non-significant (p >.05), indicating that for each group as specified in the hypotheses was normally distributed.

Homogeneity of Variances

Appendix D shows that all Levene's tests are non-significant (p>.05), indicating that the variability of scores for each group as specified in the hypotheses was similar. In other words, there was no violation of the assumption of homogeneity of variance.

3.3.2 Statistical Techniques for Testing Hypothesis

The general assumptions for parametric data as described above have been met for all the scores. This means that the samples from which the scores were obtained came from a population of equal variance, or were normally distributed with equal variance.

For Hypothesis 1 and Hypothesis 2, the subjects of the same group were tested twice, first in the pre-test and then in the post-test. Therefore, the suitable statistical technique for testing both hypotheses is a paired-samples t-test. However, there is an additional assumption for the paired-samples t-test; that is, the difference between the two scores (pre-test score and post-test score) obtained for each subject should be normally distributed (Pallant, 2001).

In this study, the assumption was tested using the Shapiro-Wilk test as previously mentioned. The result of the Shapiro-Wilk test (Appendix E) show a significant value p >.05, which indicates the difference between the two scores is normally distributed. Therefore, the paired-samples t-test can be used to test Hypothesis 1 and Hypothesis 2.

To test Hypotheses 3 to 8, a suitable technique is the two-way ANCOVA. This technique is suitable because there is an additional variable (pre-test as covariate) and two independent variables (method of instruction and students' level of achievement). However, there are two additional assumptions associated with ANCOVA that need to be tested; the linearity of the relationship between the covariate and the dependent variable and homogeneity of the covariate-dependent variable slopes.

The linearity assumption is relatively straightforward in determining the significance of the test associated with the covariate-dependent variable correlation coefficient. If there is no linear relation between dependent variable and covariate, the use of ANCOVA is not much different from ANOVA in determining the differences between the group means (Pallant, 2001).

The second assumption (the homogeneity of regression slopes) is concerned with the linear relationship between the covariate and the dependent variable, which should be at the same level for each group. The assumption of homogeneity of regression slopes (the slopes of the regression lines) can be assessed through a statistical test. A significant interaction between the covariate on each independent variable effects ($p<.05$) indicates that the assumption of homogeneity of regression coefficients has been violated. If this assumption is violated, it is more likely for Type I errors to occur. Therefore, it is suggested that two-way ANOVA is used instead of two-way ANCOVA. Table 10 simplifies the assumptions of ANCOVA for testing hypotheses. The overall assumptions are shown in Appendix F.

Table 10

Assumptions of ANCOVA

Research Hypotheses	Homogeneity of regression slopes	Linear relationship between dependent variable and covariate (Pearson Correlation)	Parametric test
H_3 and H_4	Method * Pre-test F(1,78) =1.957 , p>.05 Level * Pre-test F(1,78) =0.149 , p>.05 Method * Level *Pre-test F(1,78) =0.663 , p>.05 **Assumption is met**	Pre-test - Post-test: Correlation is significant at the 0.01 level (2-tailed). **Assumption is met**	Two-way ANCOVA
H_5 and H_6	Method * Pre-test GQ F(1,78) =4.496 , p<.05 Level * Pre-test GQ F(1,78) =0.589 , p>.05 Method * Level * Pre-test GQ F(1,78) =0.012 , p>.05 **Assumption is violated**	Pre-test GQ - Post-test GQ: Correlation is not significant. **Assumption is violated**	Two-way ANOVA
H_7 and H_8	Method * Pre-test SQ F(1,78) =0.043 , p>.05 Level * Pre-test SQ F(1,78) =2.021 , p>.05 Method * Level * Pre-test SQ F(1,78) =3.015 , p>.05 **Assumption is met**	Pre-test SQ - Post-test SQ: Correlation is significant at the 0.05 (2-tailed). **Assumption is met**	Two-way ANCOVA

Note. Symbols:
* indicates interaction.

To test Hypotheses 9 to 14, a suitable technique is the one-way ANCOVA, because there is an additional variable (pre-test as covariate) and one independent variable. Group was taken as an independent variable, which was further divided into four specific groups. The groups were (a) Group 1: High achiever students (exposed to CBI); (b) Group 2: Low achiever students (exposed to CBI); (c) Group 3: High achiever students (exposed to CAnI); and (d) Group 4: Low achiever students (exposed to CAnI). However, there were additional assumptions to be tested, as was the case with the two-way ANCOVA mentioned earlier. Table 11 shows the parametric tests for testing Hypotheses 9 to 14 after taking into account the additional assumptions of ANCOVA.

Table 11

Assumptions of ANCOVA

Research Hypotheses	Homogeneity of regression slopes	Linear relationship between dependent variable and covariate (Pearson Correlation)	Parametric test
H_9 and H_{10}	Group * Pre-test $F(3,77) = 1.023$, $p > .05$ **Assumption is met**	Pre-test - Post-test: Correlation is significant at the 0.01 level (2-tailed). **Assumption is met**	One-way ANCOVA
H_{11} and H_{12}	Group * Pre-test GQ $F(3,77) = 2.063$, $p > .05$ **Assumption is met**	Pre-test GQ – Post-test GQ Correlation is not significant **Assumption is violated**	One-way ANOVA
H_{13} and H_{14}	Group * Pre-test SQ $F(3,77) = 1.545$, $p > .05$ **Assumption is met**	Pre-test SQ – Post-test SQ Correlation is significant at the 0.05 level (2-tailed). **Assumption is met**	One-way ANCOVA

Note. Symbols:
* indicates interaction.

If there are significant differences amongst the mean scores of the groups, further statistical analysis using one-way ANOVA with planned comparisons must be conducted in order to determine which specific groups are significantly different.

3.3.5 The Similarity Between Groups

The comparison made between the CAnI and CBI groups was based on the assumption that both groups were similar (in respect to their existing knowledge of the electrochemistry concepts before exposure to treatment). The outputs of independent samples test are shown in Table 12.

Table 12

Independent samples test (Pre-test)

	Levene's Test for Equality of Variances		t-test for Equality of Means						
								95% Confidence	
	F	Sig.	t	df	Sig. (2-tailed)	Mean Diff.	Std. Error Diff.	Lower	Upper
Equal variances assumed	.532	.468	.254	83	.800	.136	.535	-.928	1.200
Equal variances not assumed			.251	73.25	.803	.136	.543	-.946	1.218

The Levene's test in Table 12 shows no significant difference, t(83) = .254 and p>.05, which indicates that the assumption of equality of variance for the pre-test scores was met. Therefore, the "Equal variances assumed" row is taken into account instead of the "Equal variances not assumed" row. The results for the independent sample t-test shows that there was no statistically significant difference between the pre-test mean score for the CAnI group and the CBI group, $t(83)= .254$, $p>.05$. Therefore, both groups were considered significantly equivalent in their existing knowledge before the treatment.

3.4 Results of Pre-test and Post-test

For this study, the effect size is calculated to identify the different strength between means. The effect size shows the magnitude of the differences between groups. The study used Cohen d, which is a measure of the size of the experiment effect or represents the percentage of nonoverlap of treated groups' scores with those of the untreated group. Table 13 shows the value of Cohen's effect size for mean differences (Cohen, 1988).

Table 13

Cohen's Effect Size

Verbal Description	Effect Size
Small	0.2
Medium	0.5
Large	0.8

Hypothesis 1

Ho_1: There is no difference between the pre-test and post-test mean scores of the students in the CAnI group

Appendix G shows the results from the paired-samples t-test procedure. The results show that there was a statistically significant increase in the post-test scores (M=13.57, SD=3.63) for students who were exposed to CAnI method compared to pre-test scores (M=3.19, SD=2.15), $t(44)= -18.02$, $p<.05$. Therefore, students in the CAnI method achieved a better post-test mean score than the pre-test mean score. For this data, the experimental conditions yield the correlation coefficient ($r = .18$) but it is not significantly correlated ($p>.05$). This implies that there is no linear relationship between the pre-test mean score and post-test mean score of the students who were exposed to CAnI.

Hypothesis 2

Ho_2: There is no difference between the pre-test and post-test mean scores of the students in the CBI group.

Appendix H for the paired-samples t-test show that there was a statistically significant increase in the post-test scores (M=10.24, SD=3.90) of the students who were exposed to CBI compared to the pre-test scores (M=3.32, SD=2.77), $t(39)= -12.66$, $p<.05$. As expected, the students in the CBI group achieved a higher post-test mean score than pre-test mean score. For this data, the post-test mean score is positively related to the pre-test mean score and yields a large correlation coefficient ($r = .51$), which indicates a linear relationship between the pre-test mean score and post-test mean score of the students who were exposed to CBI.

Hypotheses 3 and 4

Ho_3: There is no difference between the post-test mean scores of students in the CAnI and CBI groups.

Ho_4: There is no interaction effect of instructional methods and students' level of achievement in relation to the post-test mean score.

The results of the ANCOVA procedure are shown in Tables 14 and 15. The tables indicate that there was a statistically significant difference in the post-test mean scores of the students who were exposed to CAnI ($M=13.6$, $SD=3.63$) in comparison to the students who were exposed to CBI ($M=10.24$, $SD = 3.8894$); $F(1,80) = 19.70$, $p<.05$, with an effect size of .198 . Therefore, the students who were exposed to CAnI achieved a higher post-test mean score than those who were exposed to CBI. An effect size of .198 suggests that 19.8% of the differences in the post-test scores were related to the differences in the instructional methods.

Table 14

Descriptive statistics (Dependent Variable: Post-test)

Methods	Student's level of achievement	Mean	Std. Deviation	N
CBI	High achiever	11.150	3.9573	20
	Low achiever	9.325	3.7144	20
	Total	10.237	3.8994	40
CAnI	High achiever	14.292	3.8756	24
	Low achiever	12.738	3.2157	21
	Total	13.567	3.6285	45
Total	High achiever	12.864	4.1782	44
	Low achiever	11.073	3.8350	41
	Total	12.000	4.0927	85

Table 15

ANCOVA (Dependent Variable: Post-test)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta^2
Corrected Model	427.001	4	106.750	8.714	.000	.303
Intercept	3016.747	1	3016.747	246.265	.000	.755
Pre-test	131.956	1	131.956	10.772*	.002	.119
Method	241.325	1	241.325	19.700	.000	.198
Level	31.622	1	31.622	2.581	.112	.031
Interaction	8.873	1	8.873	.724	.397	.009
Error	979.999	80	12.250			
Total	13647.000	85				
Corrected Total	1407.000	84				

* $p < .05$

Table 15 also shows that there was no significant interaction effect between the instructional method and students' level of achievement in respect to the post-test scores $F(1,80)= .724$, $p>.05$, which indicates that there was no significant difference in the effect of the instructional method on the post-test scores of high and low achiever students. Both methods were equally effective for the low and high achieving students in respect to the post-test. Parallel lines as shown in Figure 19 indicate the absence of any interaction between the instructional methods and students' level of achievement. This suggests a similar pattern of the post-test mean score on the instructional methods of both high and low achiever students. In other words, the mean score of the CAnI group for both low and high achievers was greater than their counterparts in the CBI group.

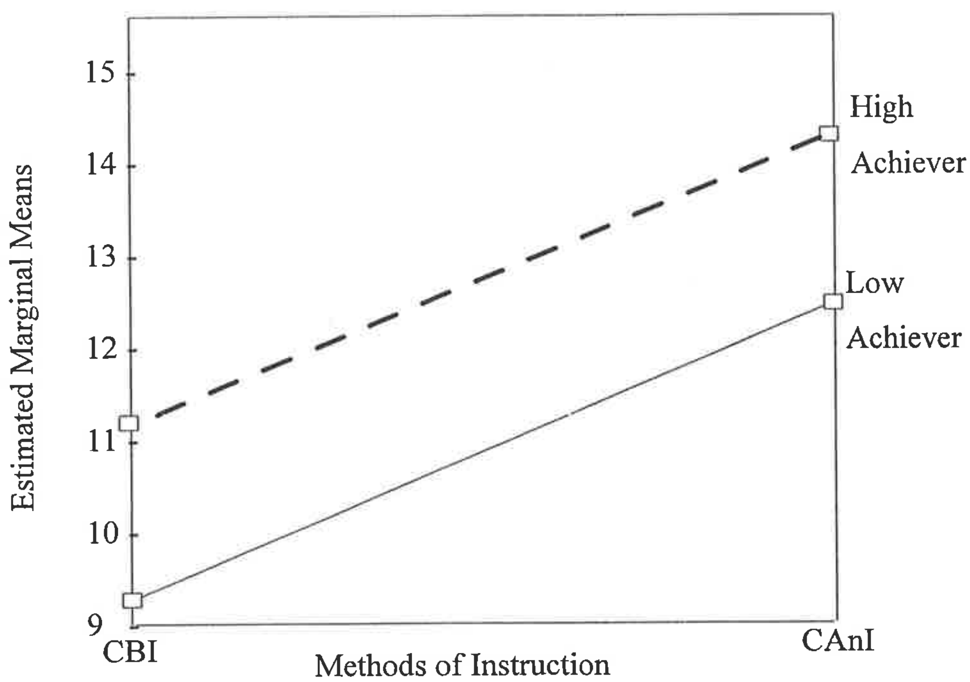


Figure 19. Estimated marginal means of post-test for High and Low Achievers.

However, there was a significant relationship between the pre-test mean score and the post-test mean score, $F(1,80)= 10.77$, $p<.05$, with an effect size of .119, which indicates that 11.9% of the differences in the post-test could be predicted from the pre-test.

Hypotheses 5 and 6

Ho_5: There is no difference between the post-test mean scores for general questions of the students in the CAnI and CBI groups.

Ho_6: There is no interaction effect of instructional methods and students' level of achievements in relation to the mean score in the post-test general questions

The results of the ANOVA procedure are shown in Tables 16 and 17. Tables 16 and 17 reveal that there was a statistically significant difference in the post-test GQ mean scores of the students who were exposed to CAnI ($M=5.39$, $SD=1.87$) compared to the students who were exposed to CBI ($M=4.25$, $SD=1.51$); $F(1,81)= 9.138$, $p<.05$ with an effect size of .101. Therefore, the students who were exposed to CAnI achieved a significantly higher post-test GQ mean score than students who were exposed to CBI. An effect size indicates that 10.1 % of the differences in the post-test GQ scores were related to the differences in the instructional methods.

Table 16

Descriptive statistics (Dependent Variable: Post-test GQ)

Methods	Student's level of achievement	Mean	Std. Deviation	N
CBI	High achiever	4.550	1.5551	20
	Low achiever	3.950	1.4409	20
	Total	4.250	1.5106	40
CAnI	High achiever	5.521	1.7905	24
	Low achiever	5.238	1.9976	21
	Total	5.389	1.8735	45
Total	High achiever	5.080	1.7386	44
	Low achiever	4.610	1.8456	41
	Total	4.853	1.7959	85

Table 17

ANOVA (Dependent Variable: Post-test GQ)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta^2
Corrected Model	31.963	3	10.654	3.612	.017	.118
Intercept	1959.505	1	1959.505	664.242	.000	.891
Method	26.958	1	26.958	9.138*	.003	.101
Level	4.117	1	4.117	1.395	.241	.017
Interaction	.532	1	.532	.180	.672	.002
Total	2272.750	85				
Corrected Total	270.912	84				

* $p < .05$

Table 17 shows that there was no significant interaction effect between the instructional methods and students' level of achievement in respect to the mean score in the post-test GQ; $F(1,81) = .180$, $p > .05$. This indicates that there is no significant difference in the effect of the instructional methods on the post-test GQ mean scores of the high and low achiever students.

Parallel lines as shown in Figure 20 indicate the absence of an interaction between the instructional methods and students' level of achievement. This suggests a similar pattern of the post-test GQ mean scores on the instructional method of both high and low achiever students. In other words, both methods were equally effective for the high and low achiever students with respect to the post-test GQ mean scores.

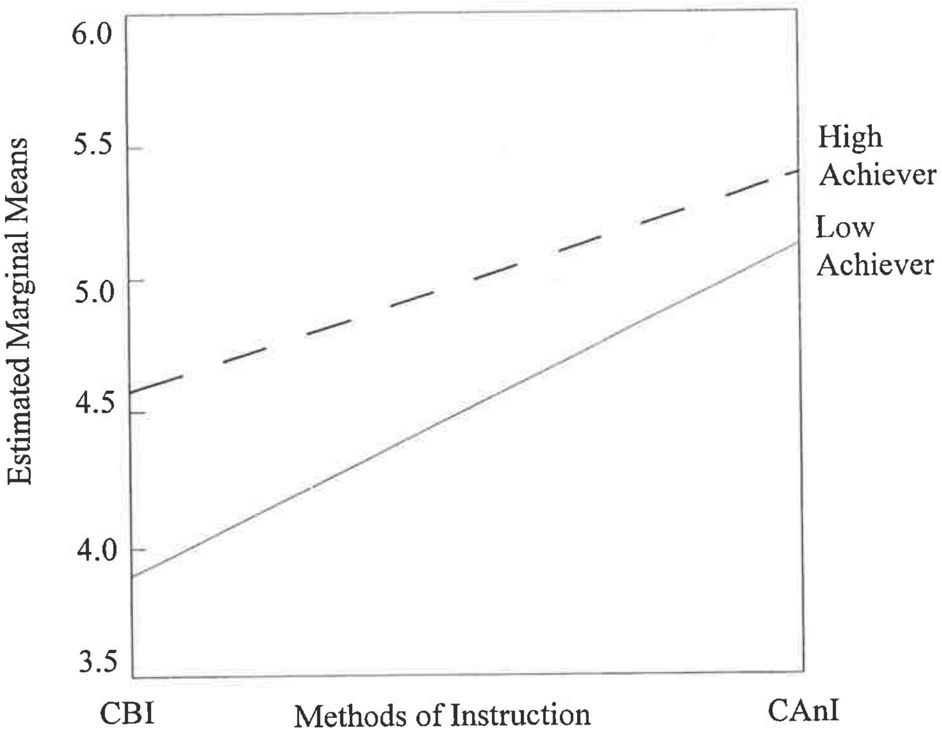


Figure 20. Estimated marginal means post-test GQ for CBI and CAnI groups

Hypotheses 7 and 8

Ho_7: There is no difference between the post-test mean scores for specific questions of the students in the CAnI and CBI groups.

Ho_8: There is no interaction effect of instructional methods and students' level of achievement in relation to mean scores in the post-test specific questions.

Tables 18 and 19 show the results of descriptive statistics and the ANCOVA procedure, which indicate a statistically significant difference in the post-test SQ mean score of the students who were exposed to CAnI (M=8.20, SD=2.85) compared to the students who were exposed to CBI (M=6.025, SD=3.0423), $F(1,80)= 13.51$, $p<.05$.), with an effect size of .144). Therefore, the students who were exposed to CAnI demonstrated a higher mean score in the post-test SQ than those who were exposed to CBI. This suggests that 14.4% of the differences in the post-test SQ mean score were related to the differences in the instructional methods.

Table 18

Descriptive statistics (Dependent Variable: Post-test SQ)

Methods	Student's level of achievement	Mean	Std. Deviation	N
CBI	High achiever	6.650	2.8521	20
	Low achiever	5.400	3.1689	20
	Total	6.025	3.0423	40
CAnI	High achiever	8.750	2.9964	24
	Low achiever	7.571	2.5995	21
	Total	8.200	2.8492	45
Total	High achiever	7.795	3.0847	44
	Low achiever	6.512	3.0588	41
	Total	7.176	3.1213	85

Table 19

ANCOVA (Dependent Variable: Post-test SQ)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta^2
Corrected Model	201.536	4	50.384	6.535	.000	.246
Intercept	819.453	1	1819.453	235.980	.000	.747
Pre-test SQ	70.176	1	70.176	9.102	.003	.102
Method	104.154	1	104.154	13.509*	.000	.144
Level	31.597	1	31.597	4.098	.046	.049
Interaction	3.020	1	3.020	.392	.533	.005
Total	5196.000	85				
Corrected Total	818.353	84				

* $p < .05$

Table 19 shows that there was no significant interaction effect between the instructional methods and the students' level of achievement with respect to the mean score in post-test SQ $F(1,80)= .39$, $p>.05$. This indicates that there was no significant difference in the effect of the instructional method on the post-test SQ mean score of the high and low achiever students. Again, this implies that both instructional methods were equally effective for the low and high achiever students with respect to the post-test SQ mean score.

Parallel lines as shown in Figure 21 indicate the absence of an interaction between the instructional method and the students' level of achievement. This suggests a similar pattern of the post-test SQ mean score on the instructional method of both high and low achiever students. In both cases, the mean score of the CAnI group was higher than the mean score of the CBI group. In other words, both methods were equally effective for low and high achiever students with respect to the post-test of SQ.

Table 19 also shows that there was a significant relationship between the pre-test SQ scores and post-test SQ scores, $F(1,80)= 9.102$, $p<.05$. with effect size of .102. In other words, 10.2% of the differences in the post-test SQ mean score could be expected from the pre-test SQ mean score.

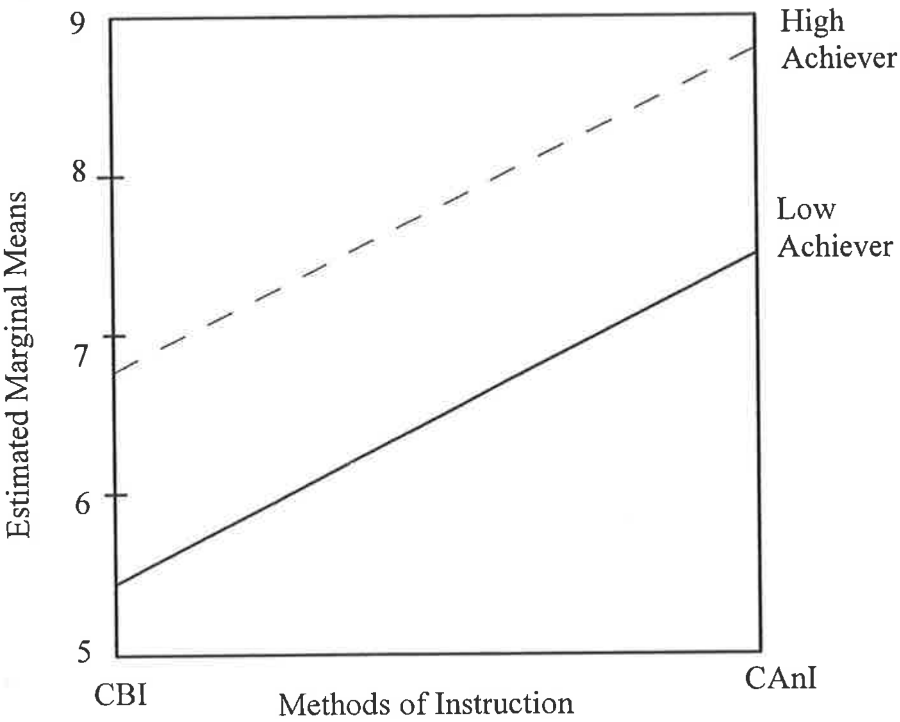


Figure 21. Estimated marginal means post-test SQ for CBI and CAnI groups.

Hypotheses 9 and 10

Ho_9: There is no difference between the post-test mean scores of the high achiever students in the CAnI and CBI groups.

Ho_{10}: There is no difference between the post-test mean scores of the low achiever students in the CAnI and CBI groups.

The results of the ANCOVA procedure which are shown in Tables 20 and 21. Table 21 indicates that there was a statistically significant difference in post-test mean score between the four groups, $F(3,80) = 7.758$, $p<.05$, with effect size of .225. This suggests that 22.5% of the post-test mean score were related to the differences between the groups. Table 21 shows that there was a significant relationship between the pre-test mean score and the post-test mean score, $F(1,80) = 10.772$, $p<.05$ with effect size of .119. This suggests that the pre-test mean score could predict 11.9% of the differences in the post-test mean score.

Table 20

Descriptive statistics (Dependent Variable: Post-test)

Groups	N	Mean	Std. Dev.	Std. Error	95% Confidence Interval for Mean		Min	Max
					Lower Bound	Upper Bound		
CBI High Achiever	20	11.150	3.9573	.8849	9.298	13.002	3.0	16.5
CBI Low Achiever	20	9.325	3.7144	.8306	7.587	11.063	3.0	16.5
CAnI High Achiever	24	14.292	3.8756	.7911	12.655	15.928	3.5	23.0
CAnI Low Achiever	21	12.738	3.2157	.7017	11.274	14.202	6.5	18.0
Total	85	12.000	4.0927	.4439	11.117	12.883	3.0	23.0

Table 21

ANCOVA (Dependent Variable: Post-test)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta^2
Corrected Model	427.001	4	106.750	8.714	.000	.303
Intercept	3016.747	1	3016.747	246.265	.000	.755
Pre-test	131.956	1	131.956	10.772	.002	.119
Group	285.095	3	95.032	7.758*	.000	.225
Error	979.999	80	12.250			
Total	13647.000	85				
Corrected Total	1407.000	84				

* $p < .05$

The results from one-way ANOVA with planned comparisons are shown in Tables 22, 23, and 24. Table 22 shows that there was a significant difference in the post-test mean score across the four groups; $F(3,81)= 7.16$. Table 23 shows the positive weight against negative weight. This is to ensure that contrast 1, compares Group 1 (CBI high achiever) and Group 3 (CAnI high achiever), whereas contrast 2 compares Group 2 (CBI low achiever) and Group 4 (CAnI low achiever). As the Levene's test shows that the different was not significant, the "Assume equal variances" row in Table 24 is then considered.

For contrast 1, planned comparisons indicate that the mean score of Group 1 ($M=11.15$, $SD=3.96$) (see Table 20) was significantly different from Group 3 ($M=14.29$, $SD=3.88$); $t(81)=-2.80$, $p< .05$. This means that exposure to CAnI significantly increased the mean score of the high achiever students of the CAnI group compared to the high achiever students of the CBI group.

Table 22

ANOVA for post-test

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	295.045	3	98.348	7.164*	.000
Within Groups	1111.955	81	13.728		
Total	1407.000	84			

* $p < .05$

Table 23

Planned comparisons (Contrast Coefficients)

	CAnI and Conventional			
Contrast	CBI High achiever	CBI Low achiever	CAnI High Achiever	CAnI Low Achiever
1	1	0	-1	0
2	0	1	0	-1

Table 24

Contrast tests (Post-test)

	Contrast	Value of Contrast	Std. Error	t	df	Sig. (2-tailed)
Assume equal variances	1	-3.142	1.1218	-2.801	81	.006
	2	-3.413	1.1576	-2.948	81	.004
Does not assume equal variances	1	-3.142	1.1870	-2.647	40.262	.012
	2	-3.413	1.0873	-3.139	37.604	.003

For contrast 2, planned comparisons indicated that the mean score of Group 2 (M=9.32, SD=3.71) (Table 20) was significantly different from Group 4 (M=12.74, SD=3.22); $t(81)=-2.95$, $p< .05$. Contrast 2 shows that exposure to CAnI method significantly increased the mean score of the low achiever students of the CAnI group compared to the low achiever students of the CBI group.

Therefore, the high achiever students who were exposed to CAnI achieved a higher mean score in the post-test than the high achiever students who were exposed to CBI. Meanwhile, the low achiever students who were exposed to CAnI also achieved a higher mean score in the post-test than the low achiever students who were exposed to CBI. In summary, there was an overall effect of CAnI on the high and low achiever students compared to CBI with respect to the post-test mean score.

Hypotheses 11 and 12

Ho_{11}: There is no difference between the post-test mean scores for general questions of the high achiever students in the CAnI and CBI groups.

Ho_{12}: There is no difference between the post-test mean scores for general questions of the low achiever students in the CAnI and CBI groups.

A one-way ANOVA was conducted to explore the impact of Groups 1, 2, 3 and 4 in the post-test GQ mean score. The results of the ANOVA procedure with planned comparisons are shown in Tables 25, 26, 27, and 28.

Table 25

Descriptive (Post-test GQ)

Groups	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Min	Max
					Lower Bound	Upper Bound		
CBI High Achiever	20	4.550	1.5551	.3477	3.822	5.278	1.0	7.0
CBI Low Achiever	20	3.950	1.4409	.3222	3.276	4.624	2.0	7.0
CAnI High Achiever	24	5.521	1.7905	.3655	4.765	6.277	0.0	8.0
CAnI Low Achiever	21	5.238	1.9976	.4359	4.329	6.147	1.5	9.0
Total	85	4.853	1.7959	.1948	4.466	5.240	0.0	9.0

Table 26

ANOVA (Post-test GQ)

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	31.963	3	10.654	3.612*	.017
Within Groups	238.949	81	2.950		
Total	270.912	84			

* p < .05

Table 27

Contrast coefficients

	CAnI and CBI			
Contrast	CBI High Achiever	CBI Low Achiever	CAnI High Achiever	CAnI Low Achiever
1	1	0	-1	0
2	0	1	0	-1

Table 28

Contrast tests (Post-test GQ)

	Contrast	Value of Contrast	Std. Error	t	df	Sig. (2-tailed)
Assume equal variances	1	- .971	.5200	-1.867	81	.066
	2	-1.288	.5366	-2.400	81	.019
Does not assume equal variances	1	- .971	.5045	-1.924	41.913	.061
	2	-1.288	.5421	-2.376	36.390	.023

Table 26 shows that there was a significant difference in the post-test GQ scores of the four groups (F (3,81) = 3.612, p <.05). However, the result did not show which specific groups were significantly different. Meanwhile, Table 27 shows the positive weight against negative weight, which compares Group 1 and 3, and Group 2 and 4. As the Levene's test shows that the different was not significant (p>.05), the "Assume equal variances" row in Table 28 is then considered.

For contrast 1, planned comparisons indicated that the mean score of Group 1 (M=4.55, SD=1.55) (Table 25) was not significantly different from Group 3 (M=5.52, SD=1.79) ; t(81)=-1.87, p>.05). This means that there was no significant difference between the mean score (post-test GQ) of the high achiever students of the CAnI group and the high achiever students of the CBI group.

For contrast 2, planned comparisons indicated that the mean score of Group 2 (M=3.95, SD=1.44) (Table 25) was significantly different from Group 4 (M=5.24, SD=1.20); t(81)=-2.40, p<.05). This shows that exposure to CAnI significantly increased the mean score (post-test GQ) of low achiever students compared to the low achiever students who were exposed to CBI.

It can be concluded that there was no significant difference in the mean score of the high achiever students who were exposed to both methods of instruction with respect to the post-test GQ. In contrast, the low achiever students who were exposed to CAnI demonstrated a higher mean score in the post-test GQ was no effect of CAnI on the high achiever students compared to the low achiever students with respect to the post-test GQ mean score.

Hypotheses 13 and 14

Ha_{13}: There is no difference between the post-test mean scores for specific questions of the high achiever students in the CAnI and CBI groups.

Ha_{14}: There is no difference between the post-test mean scores for specific questions of the low achiever students in the CAnI and CBI groups.

The results of the ANCOVA procedure are shown in Tables 29 and 30.

Table 29

Descriptive (Post-test SQ)

Groups	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Min	Max
					Lower Bound	Upper Bound		
CBI High Achiever	20	6.650	2.8521	.6377	5.315	7.985	2.0	12.0
CBI Low achiever	20	5.400	3.1689	.7086	3.917	6.883	1.0	12.0
CAnI High Achiever	24	8.750	2.9964	.6116	7.485	10.015	3.0	17.0
CAnI Low Achiever	21	7.571	2.5995	.5672	6.388	8.755	2.0	12.0
Total	85	7.176	3.1213	.3385	6.503	7.850	1.0	17.0

Table 30

ANCOVA (Post-test SQ)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta^2
Corrected Model	201.536	4	50.384	6.535	.000	.246
Intercept	819.453	1	1819.453	235.980	.000	.747
Pre-test (SQ)	70.176	1	70.176	9.102	.003	.102
Group	140.447	3	46.816	6.072*	.001	.185
Error	616.817	80	7.710			
Total	5196.000	85				
Corrected Total	818.353	84				

* $p < .05$

Table 30 shows that there was a significant difference in the post-test SQ mean score between Groups 1, 2, 3, and 4, $F(3,80)= 6.072$, $p<.05$, effect size of .185. This suggests that 18.5% of the post-test specific questions scores were related to the differences between the groups. Table 30 also shows that there was a significant relationship between the pre-test SQ mean score and the post-test SQ mean score, $F(1,80)= 9.102$, $p<.05$ with effect size of .102. Therefore, 10.2% of the differences in the post-test SQ score could be predicted by the pre-test SQ score.

The results of the ANOVA procedure with planned comparisons are shown in Tables 31, 32, and 33.

Table 31

ANOVA (Post-test SQ)

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	131.360	3	43.787	5.163*	.003
Within Groups	686.993	81	8.481		
Total	818.353	84			

* $p < .05$

Table 32

Contrast coefficients for planned comparisons

Contrast	Groups			
	CBI High achiever	CBI Low achiever	CAnI High Achiever	CAnI Low Achiever
1	1	0	-1	0
2	0	1	0	-1

Table 33

Contrast tests (Post-test SQ)

	Contrast	Value of Contrast	Std. Error	t	df	Sig. (2-tailed)
Assume equal variances	1	-2.100	.8817	-2.382	81	.020
	2	-2.171	.9099	-2.386	81	.019
Does not assume equal variances	1	-2.100	.8836	-2.377	41.219	.022
	2	-2.171	.9077	-2.392	36.798	.022

Table 31 shows that there was a significant difference in the post-test SQ mean scores between groups, F (3,81)= 5.163, p< .05. As the Levene's test was not significant (p>.05), the "Assume equal variances" row is considered. For contrast 1 in Table 33, planned comparisons indicated that the mean score of Group 1 (M=6.65, SD=2.85) was significantly different from Group 3 (M=8.75, SD=2.99); t (81)=-2.38, p< .05. This means that exposure to CAnI significantly increased the mean score (post-test SQ) of the high achiever students compared to the high achiever students of the CBI group.

For contrast 2 in Table 33, planned comparisons indicated that the mean score of Group 2 (M=5.40, SD=3.17) (Table 18) was significantly different from Group 4 (M=7.57, SD=2.60); t(81)=-2.386, p<.05). Contrast 2 shows that exposure to CAnI significantly increased the mean score (post-test SQ) of the students of the CAnI group compared to the low achiever students of the CBI group.

In summary, both high and low achiever students who were exposed to CAnI achieved higher mean scores in the post-test SQ than the high and low achiever students who were exposed to CBI. There was an overall effect of CAnI on the high and low achiever students compared to CBI in respect to the post-test SQ mean scores.

3.5 Results of Questionnaire

Table 34 - 38 represent the results in terms of percentage for agreement ("Agree" and "Strongly Agree") and disagreement ("Disagree" and "Strongly Disagree") for each item in the closed questionnaires. The percentage of "Not Sure" was not taken into consideration in the percentage of agreement or disagreement.

Theme 1: Identify respondents' misconceptions

One of the teacher's roles under the constructivist approach is to encourage students to actively express and discuss their ideas through class discussion. Table 34 represents the results in terms of percentage for agreement and disagreement for theme 1. Question 2b in Table 34 shows that nearly all the respondents in the CAnI group (91.1%, mean = 4.2) agreed that they were given the opportunity to contribute in class discussion compared to only 67.5% (mean = 3.7) of the respondents in the CBI group. Question 7 provided an insight into the aspect of the strategy to reduce students' misconception. 91.1 % (mean = 4.0) of the CAnI respondents agreed that the teacher's explanation using animations corrected some of their misconceptions about chemical cells, compared to only 57.5% (mean = 3.6) shown by the respondents in the CBI group. Responses to Question 15 show that most respondents in the CAnI and the CBI groups (77.8% and 70.0% respectively) acknowledged the importance of class discussion in helping them to understand more about the content knowledge.

Questions 7, 14 and 20 show both groups agreed (mean > 3.6) that they experienced some misunderstandings during the lessons. Based on the responses to Question 7, 91.1% of the respondents in the CAnI groups agreed that the teacher's presentation using animations made them aware of their misunderstandings of electrochemistry concepts compared to only 65.0% of respondents in the CBI group. These findings suggest that the majority of respondents in both groups were at least aware of their misconceptions. Question 19 shows clearly that almost 90% (mean = 4.2) of the respondents in the CAnI group strongly agreed that the teacher's presentation through the use of animation increased their interest in learning the content knowledge compared to only 47.5% (mean = 3.2) of the respondents in the CBI group.

Table 34

Percentage of response for groups CAnI (question a) and CBI (question b) for Theme 1- Identifying respondents' misconceptions

Theme 1: Identify respondents' misconceptions		Strongly Agree 5		Agree 4		Not Sure 3		Disagree 2		Strongly Disagree 1		Result	Mean
		(n)	%	(n)	%	(n)	%	(n)	%	(n)	%	%	
2a	The teacher encouraged the students to actively give ideas and comments in class discussions.	5	12.5	22	55	8	20	5	12.5	-	-	67.5 (Agree)	3.7
2b	The teacher encouraged the students to actively give ideas and comments in class discussions.	13	28.9	28	62.2	3	6.7	1	2.2	-	-	91.1 (Agree)	4.2
7a	The teacher's explanation using transparencies corrected some of my misunderstandings about electrochemical cells.	3	7.5	20	50	15	37.5	2	5	-	-	57.5 (Agree)	3.6
7b	The teacher's explanation using animations corrected some of my misunderstandings about electrochemical cells.	6	13.3	35	77.8	4	8.9	-	-	-	-	91.1 (Agree)	4.0
14a	I can identify my misunderstandings of the reactions occurring at the electrodes after attending the class.	4	10	33	82.5	3	7.5	-	-	-	-	92.5 (Agree)	4.0
14b	I can identify my misunderstandings of the reactions occurring at the electrodes after attending the class.	10	22.2	29	64.4	5	11.1	1	2.2	-	-	86.6 (Agree)	4.1
15a	I do not think that the class discussion helped me to understand more about electrochemical cells.	-	-	7	17.5	5	12.5	20	50	8	20	70.0 (Disagree)	2.3
15b	I do not think that the class discussion helped me to understand more about electrochemical cells.	-	-	5	11.1	5	11.1	28	62.2	7	15.6	77.8 (Disagree)	2.2

Table 34 (continued)

Theme 1: Identify respondents' misconceptions		Strongly Agree 5		Agree 4		Not Sure 3		Disagree 2		Strongly Disagree 1		Result	Mean
		(n)	%	(n)	%	(n)	%	(n)	%	(n)	%	%	
19a	The teacher's presentation by using transparencies increased my interest in learning electrochemical cells.	-	-	19	47.5	14	35	4	10	3	7.5	47.5 (Agree)	3.2
19b	The teacher's presentation by using animation increased my interest in learning electrochemical cells.	16	35.6	24	53.3	5	11.1	-	-	-	-	88.9 (Agree)	4.2
20a	I was not aware that I had some misunderstandings until I attended the class.	1	2.5	24	60	13	32.5	2	5	-	-	62.5 (Agree)	3.6
20b	I was not aware that I had some misunderstandings until I attended the class.	10	22.2	20	44.4	11	24.4	4	8.9	-	-	66.6 (Agree)	3.8

Theme 2: Guide towards new concepts

In the constructivist teaching situation, students need guidance or scaffolding from the teacher in order to internalize concepts and new ideas. Therefore, one of the teachers' roles is to provide organized materials and assistance to promote this internalization process.

Table 35 represents the results in terms of percentage for agreement and disagreement for theme 2. In relation to this, Questions 3, 8 and 9 indicated clues that more than 80% (mean ≥ 4.0) of the respondents in the CAnI group agreed that animations could be an effective tool to understand the connection between concepts in comparison to only 35% to 58% of the respondents in the CBI group. On the other hand, Question 23 shows that 85% (mean = 4.0) of the respondents in the CBI group agreed that the teacher gave a clear explanation of how the concentration of electrolyte affects the chemical reactions compared to 66.7% (mean = 3.7) of the respondents in the CAnI group. One possible explanation is that text-based animations, constructed to display only symbolic level of presentations were not much more preferred than the direct explanation using transparencies. This suggests that the students seem to prefer a teacher who teaches the factors affecting electrolysis for aqueous solution in simplified forms using transparencies than one who uses text-based animations.

Table 35

Percentage of response for groups CAnI (question a) and CBI (question b) for Theme 2- Guide towards new concepts

Theme 2: Guide towards new concepts.		Strongly Agree 5		Agree 4		Not Sure 3		Disagree 2		Strongly Disagree 1		Result	Mean
		(n)	%	(n)	%	(n)	%	(n)	%	(n)	%	%	
3a	The teacher systematically introduced one concept after another using the transparencies.	6	15	17	42.5	17	42.5	-	-	-	-	57.5 (Agree)	3.7
3b	The teacher systematically introduced one concept after another using the animations.	17	37.8	22	48.9	6	13.3	-	-	-	-	86.7 (Agree)	4.2
8a	The transparencies were clear enough for me to see the connection between the concepts.	4	10	10	25	25	62.5	1	2.5	-	-	35.0 (Agree)	3.4
8b	The animations were clear enough for me to see the connection between the concepts.	11	24.4	26	57.8	7	15.6	1	2.2	-	-	82.2 (Agree)	4.0
9a	The teacher broke up the complex and abstract concepts by using transparencies, making it easier to understand.	1	2.5	13	32.5	25	62.5	1	2.5	-	-	35.0 (Agree)	3.6
9b	The teacher broke up the complex and abstract concepts by using animation, making it easier to understand.	10	22.2	32	71.1	1	2.2	2	4.4	-	-	93.3 (Agree)	4.1

Table 35 (continued)

Theme 2: Guide towards new concepts.		Strongly Agree 5		Agree 4		Not Sure 3		Disagree 2		Strongly Disagree 1		Result	Mean
		(n)	%	(n)	%	(n)	%	(n)	%	(n)	%	%	
23a	The teacher gave a clear explanation of how the concentration of electrolyte affects the chemical reaction at the cathode.	4	10	30	75	6	15	-	-	-	-	85.0 (Agree)	4.0
23b	The teacher gave a clear explanation of how the concentration of electrolyte affects the chemical reaction at the cathode.	4	8.9	26	57.8	14	31.1	1	2.2	-	-	66.7 (Agree)	3.7

Theme 3: Provide plausible learning materials

A teacher must provide plausible explanation in order to reconcile students' misconceptions or cognitive conflicts, especially if they are dissatisfied with their existing concepts and cannot get satisfactory clarifications. Table 36 represents the results in terms of percentage for agreement and disagreement for theme 3. Questions 5, 13 and 18 show both groups' responses to the plausibility of three areas of content knowledge (the differences between cells, the production of sodium, and the function of a salt bridge).

The high percentage of agreement (87% and 71%) for Questions 5 and 18 respectively and the high percentage of disagreement of 66% (question was expressed as a negative statement) for Question 13 shown by the CAnI group give an insight into the advantage of using animations in providing plausible materials in teaching the three concepts mentioned above. On the other hand, as a comparison, the percentages obtained from the CBI group were only 42%, 38% and 55%, respectively. The high percentage of agreement shown by the CAnI group for Question 4 (88.9%, mean 4.3) and the low percentage of agreement shown by the CBI group (35%, mean 3.4) suggest that animation was accepted as a more plausible teaching and learning method.

Table 36

Percentage of response for groups CAnI (question a) and CBI (question b) for Theme 3 – Provide plausible learning materials

Theme 3: Provide plausible learning materials		Strongly Agree 5		Agree 4		Not Sure 3		Disagree 2		Strongly Disagree 1		Result	Mean
		(n)	%	(n)	%	(n)	%	(n)	%	(n)	%	%	
4a	I think the transparencies shown in the class made learning electrochemical cells much easier.	3	7.5	11	27.5	23	57.5	3	7.5	-	-	35.0 (Agree)	3.4
4b	I think the animations shown in the class made learning electrochemical cells much easier.	21	46.7	19	42.2	3	6.7	2	4.4	-	-	88.9 Agree)	4.3
5a	The transparencies presented, guided me to understand the differences between electrolytic and galvanic cells.	2	5	15	37.5	23	57.5	-	-	-	-	42.5 (Agree)	3.5
5b	The animations presented, guided me to understand the differences between electrolytic and galvanic cells.	10	22.2	29	64.4	6	13.3	-	-	-	-	86.6 (Agree)	4.1
13a	Based on the teacher's explanation using transparencies, I cannot relate the electrolytic cells to the production of sodium.	-	-	1	2.5	24	60	12	30	3	7.5	37.5 (Disagree)	2.6
13b	Based on the teacher's explanation using animation, I cannot relate the electrolytic cells to the production of sodium.	-	-	3	6.7	12	26.7	25	55.6	5	11.1	66.7 (Disagree)	2.3

Table 36 (continued)

Theme 3: Provide plausible learning materials		Strongly Agree 5		Agree 4		Not Sure 3		Disagree 2		Strongly Disagree 1		Result	Mean
		(n)	%	(n)	%	(n)	%	(n)	%	(n)	%	%	
18a	I found it was hard to see the function of the salt bridge from the transparencies.	-	-	8	20	10	25	14	35	8	20	55.0 (Disagree)	2.4
18b	I found it was hard to see the function of the salt bridge from the animations.	1	2.2	4	8.9	8	17.8	21	46.7	11	24.4	71.1 (Disagree)	2.2

Theme 4: Provide intelligible learning materials

According to Blank (2000), a concept is considered intelligible to students when they can explain it in their own words. Table 37 represents the results in terms of percentage for agreement and disagreement for theme 4. In this sense, students know the meaning of the concept and it makes sense to them. Questions 1, 16, 21, 22 and 24 attempted to capture how the respondents understood specific concepts (movement of electrons and the process of electroplating) and electrochemistry concepts in general. Questions 1, 21 and 24 show that more than 80% of the respondents in CAnI and more than 60% of the respondents in CBI agreed that the animations (for CAnI group) and transparencies (for CBI group) provided intelligible explanation. However, when asked about a specific abstract concept (movement of electrons) in Question 16, 93.3% (mean = 4.3) of respondents in the CAnI group agreed that they could easily understand the concept through animations compared to only 35% (mean = 3.2) of the respondents in the CBI group.

Table 37

Percentage of response for groups CAnI (question a) and CBI (question b) for Theme 4 – Provide intelligible learning materials

Theme 4: Provide intelligible learning materials		Strongly Agree 5		Agree 4		Not Sure 3		Disagree 2		Strongly Disagree 1		Result	Mean
		(n)	%	(n)	%	(n)	%	(n)	%	(n)	%	%	
1a	I found the teacher's presentation using transparencies useful in my understanding of electrochemistry concepts.	5	12.5	28	70	6	15	1	2.5	-	-	82.5 (Agree)	3.9
1b	I found the teacher's presentation using animations useful in my understanding of electrochemistry concepts.	20	44	21	46.7	4	8.9	-	-	-	-	90.7 (Agree)	4.4
16a	I could easily understand the movement of electrons from one electrode to another in the electrolytic cell through the transparencies.	1	2.5	13	32.5	20	50	6	15	-	-	35.0 (Agree)	3.2
16b	I could easily understand the movement of electrons from one electrode to another in the electrolytic cell through the animations.	18	40	24	53.3	2	4.4	1	2.2	-	-	93.3 (Agree)	4.3
21a	I could easily understand the logic of my teacher's explanation through the transparencies.	1	2.5	23	57.5	15	37.5	1	2.5	-	-	60.0 (Agree)	3.6
21b	I could easily understand the logic of my teacher's explanation through the animations.	10	22.2	30	66.7	4	8.9	1	2.2	-	-	88.9 (Agree)	4.1
22a	I did not have a problem to comprehend the process of electroplating from the transparencies shown in the class.	-	-	15	37.5	19	47.5	6	15	-	-	37.5 (Agree)	3.2
22b	I did not have a problem to comprehend the process of electroplating from the animation shown in the class.	4	8.9	22	48.9	18	40	1	2.2	-	-	57.8 (Agree)	3.6
24a	I think that the transparencies shown in the class were understandable and made sense to me.	3	7.5	21	52.5	10	25	5	12.5	1	2.5	60.0 (Agree)	3.5
24b	I think that the animations shown in the class were understandable and made sense to me.	16	35.6	25	55.6	4	8.9	-	-	-	-	91.2 (Agree)	4.3

Theme 5: Provide fruitful learning materials

Duit and Treagust (2003) explained "for a concept to be fruitful, it must first be intelligible and plausible and should be seen as something useful to solve problems' (p.677). Table 38 represents the results in terms of percentage for agreement and disagreement for theme 5. Questions 6, 10, 11 and 12 were concerned with the fruitfulness of concepts (the use of the electrochemical series; to find the overall redox reaction; and to predict the reactions). The percentages of the CAnI group in Question 10 (64.4%, mean = 2.3), Question 11 (84.4%, mean = 4.0) and Question 12 (60%, mean = 3.7) were higher than the corresponding percentages shown by the CBI group; 57% (mean = 2.4), 47% (mean = 3.6) and 28% (mean = 3.2) respectively. These findings suggest that CAnI has an advantage over CBI as a more fruitful presentation, which encourages the solving of problems in a variety of new situations and conditions.

Question 6 (question is expressed in a negative statement) reveals that the percentage of disagreement for the CBI group (70%, mean = 2.2) was higher than for the CAnI group (53.3%, mean = 2.6). This suggests that respondents in the CBI group might perceive that it was easier to understand the electrochemical series shown through the transparency and expressed through a direct verbal explanation. The respondents who viewed the text-based animation of the electrochemical series were less likely to understand the electrochemical series.

Table 38

Percentage of response for groups CAnI (question a) and CBI (question b) for Theme 5 – Provide fruitful learning materials

Theme 5: Provide fruitful learning materials		Strongly Agree 5		Agree 4		Not Sure 3		Disagree 2		Strongly Disagree 1		Result	Mean
		(n)	%	(n)	%	(n)	%	(n)	%	(n)	%	%	
6a	I do not understand how to use the electrochemical series even after attending the class.	-	-	-	-	12	30	23	57.5	5	12.5	70.0 (Disagree)	2.2
6b	I do not understand how to use the electrochemical series even after attending the class.	3	6.7	6	13.3	12	26.7	19	42.2	5	11.1	53.3 (Disagree)	2.6
10a	It was hard to understand how to find the overall redox reaction from the teacher's use of transparencies.	-	-	3	7.5	14	35	20	50	3	7.5	57.5 (Disagree)	2.4
10b	It was hard to understand how to find the overall redox reaction from the teacher's use of animations.	2	4.4	4	8.9	10	22.2	19	42.2	10	22.2	64.4 (Disagree)	2.3
11a	The transparencies used by the teacher helped me to predict the process occurring at the anode and the cathode.	1	2.5	18	45	20	50	1	2.5	-	-	47.5 (Agree)	3.6
11b	The animations used by the teacher helped me to predict the process occurring at the anode and the cathode.	9	20	29	64.4	6	13.3	1	2.2	-	-	84.4 (Agree)	4.0
12a	I think I can write the spontaneous redox reactions occurring in the galvanic cells after attending the class.	-	-	11	27.5	24	60	5	12.5	-	-	27.5 (Agree)	3.2
12b	I think I can write the spontaneous redox reactions occurring in the galvanic cells after attending the class.	7	15.6	20	44.4	16	35.6	2	4.4	-	-	60 (Agree)	3.7

3.6 Discussion and Conclusion

The findings and analysis from the study show a positive benefit of using animations to teach conceptual change of electrochemistry concepts. It is clear that the students in the CAnI group performed better in the post-test compared to the students in the conventional method. Parametric tests revealed that the students who were exposed to CAnI demonstrated significantly better post-test mean scores, compared to their counterparts in the conventional group. This suggests that the students in the CAnI group experienced a strong conceptual change. Specifically, exposure to CAnI significantly increased the post-test mean score of the high and low achiever students of the CAnI group compared to the high and low achiever students of the CBI group.

The findings show that the better post-test performance of the CAnI group has nothing to do with differences in the pre-test score, as the Pearson correlation shows no significant relationship between the pre-test and post-test. Furthermore, the high and low achiever students in the CAnI group demonstrated better performance in the overall post-test scores compared to the high and low achiever students in the CBI group. Therefore, the main hypothesis, which postulated that CAnI improved students' conceptual change, was supported.

In CAnI, the teacher encourages active learning through collective discussion with the use of animations. This strategy seems to help the construction of knowledge among the students in the experimental group. The collective discussion approach, derived from the social constructivist view of learning, helps students to recognize and evaluate their own ideas, as compared to new concepts. As students are aware of the strengths and weaknesses of their ideas, they become more ready to restructure them.

The results of the questionnaire help to explain the students' perceptions toward CAnI and CBI, respectively. From the analysis of the questionnaire, CAnI is perceived by the students to provide greater opportunities for collective discussion and hence greater assistance to promote their conceptual. Furthermore, the high percentage of agreement in the questionnaire that claimed that they were unable to imagine chemical phenomena from the teacher's presentation using animations shown provided an insight into the effectiveness of using animations in presenting electrochemical concepts. The use of animations to present dynamic and abstract concepts and processes in electrochemistry helped the students to gain a better understanding at the macroscopic and microscopic levels (Burke et al., 1998).

The use of traditional formal instruction in presenting and explaining facts, such as factors affecting electrolysis for aqueous solutions and the electrochemical series were preferred over text-based animations. Perhaps, presenting text-based animations is not much different from conventional overhead transparencies. The findings showed that direct presentation of chemical facts through transparencies was positively perceived by students in the control group in giving an initial understanding of the facts. Furthermore, the text-based animations as viewed by the students in the CAnI group did not contribute to the students' ability to visualize any abstract and dynamic concept. This finding indicates that the text-based animations do not necessarily affect students' understanding of the factual knowledge. This might well be a limitation of using text-based animation in chemical instruction.

To conclude, this study has provided significant evidence to support the value of using CAnI in teaching for conceptual change. Analysis has revealed that the students who were exposed to CAnI have better post-test mean scores and overall positive responses to the fundamental concepts of electrochemistry than those who were exposed to CBI. Overall, regardless of the students' level of achievement, these findings clearly indicate that CAnI had positive effects on the subjects' performance for both the general and specific post-test questions.

PART IV

QUALITATIVE ANALYSIS

4.0 Introduction

The focus of this part of the study is to describe and analyze the qualitative data to see if CAnI exposure did enhance the conceptual change in first-semester science matriculation students at the Matriculation Centre, International Islamic University (IIU), Malaysia. According to Merriam (1998), a qualitative approach seeks to discover in-depth understanding and description of an individual's subject perspectives. This study employed questionnaires specifically designed to reflect subjects' perceptions regarding CAnI and CBI, and interviews to gain an in-depth and comprehensive understanding of the conceptual change experienced by an individual interviewee during instruction. This chapter describes the following aspects in detail:

1. Focus of analysis.
2. Open-ended questionnaire.
3. Interview.
4. Procedures.
5. Results and discussion.
6. Conclusion.

4.1 Focus of Analysis

This qualitative part of the study has two foci. The first focus is to explore students' perceptions towards CAnI and CBI in the teaching of electrochemistry, respectively. The following question was posed to specifically address this first focus:

What were the students' perceptions towards CAnI and CBI, respectively?

The second focus aims to examine the conceptual change under CAnI and CBI. A combination of interview transcripts and the pre-test and post-test written answers are used to examine the subjects' conceptual change. The following research questions were posed to specifically address the second focus:

To what extent did CAnI enhance students' conceptual change compared to CBI?

In order to examine each student's conceptual change, emphasis is given to four areas used to identify what might be the states of conceptual change. These four areas are:

1. student's existing ideas;
2. student's rationality in accepting or rejecting new concepts;
3. the status of ideas held by students; and
4. student's conceptual change.

4.2 Open-ended Questionnaire

The open-ended questionnaire, consisting of short answer questions, was used to obtain the subjects' responses and personal comments about the strengths and weaknesses of CAnI and CBI in their own words. In addition, it also serves as a means to seek suggestions on how to improve each method of instruction. There are two types of questionnaires, one each for the CBI and CAnI groups. Both questionnaires are identical except the word 'transparency' used for the CBI group and the word 'animation' used for the CAnI group.

The questions for the CBI group were:

1. Identify one or two things that you liked about the teacher's presentation using transparencies (and whiteboard) and why?
2. Identify one or two things that gave you problems in understanding the teacher's presentation using transparencies and why?
3. What aspects of the teacher's presentation have been most helpful in improving your understanding of electrochemistry concepts? Please explain by giving at least two examples.
4. Please give at least one suggestion of how you think that the teacher's presentation using transparencies (and whiteboard) can be improved.

The questions for the CAnI group were:

1. Identify one or two things that you liked about the teacher's presentation using animations and why?
2. Identify one or two things that gave you problems in understanding the teacher's presentation using animations and why?
3. What aspects of the teachers' presentation have been most helpful in improving your understanding of electrochemistry concepts? Please explain by giving at least two examples.
4. Please give at least one suggestion of how you think that the teacher's presentation using animations can be improved.

4.3 Interview

The purposes of the interviews in this study were (a) to examine the interviewees' ideas or thinking behind their pre-test and post-test written answers, and (b) to examine the interviewees' ability to reason scientifically when confronted with probing questions as evidence of their conceptual change. In order to obtain in-depth explanation relating to conceptual change, the interviewer encouraged the interviewees to describe reasons at the symbolic, macroscopic and microscopic levels. The format of the interview questions used in this study took into account the following factors suggested by Cohen et al. (2000, p.174):

1. The objectives of the interview.
2. The nature of the subject matter.
3. Whether the interviewer is dealing with facts, opinion or attitudes.
4. Whether specificity or depth is sought.
5. The respondent's level of education.
6. The kind of information expected.

In this study, the questions were focused on each interviewee's written answers in the pre-test and the post-test. Follow-up questions were then posed to obtain in-depth, specific information as well as to probe the interviewee's understanding, reasoning and strategies used when answering the pre-test and post-test questions. The tricky part of interviewing is to choose the best questions to ask the interviewees and to encourage them to give full responses. According to Bell, Osborne and Tasker (1985, p.152) 'questions need to be easy to answer rather than difficult, neutral rather than leading, but on the other hand penetrating rather than superficial".

Non-directive is one interview criterion relevant to this study. Non-directive refers to the sequence of asking questions. In this study, the factual question based on the interviewee's pre-test and post-test written answers was first asked, in order to avoid "the interviewer's frame of reference being imposed on the interviewee's viewpoint" (Flick, 1998, p.77), then followed by in-depth probing questions. Each interviewee was asked to give clear answers, but no attempt was made to guide him or her in terms of correct answers. In the context of this study, questions such as "What made you choose zinc as a positive electrode?" provided opportunities for the interviewee to explain whatever reasons he/she used for choosing zinc as a positive electrode.

Having considered such factors, this study used focused interview formats, adapted from clinical interviews, interviews-about-instances (IAI) and interviews-about-events (IAE). The aim of such interviews is to elicit interviewee responses, which "are spontaneous rather than forced, are highly specific and concrete rather than diffuse and general, and are self-revealing and personal rather than superficial" (Kidder & Judd, 1986, p.274). Kidder and Judd (1986) further mentioned that focused interview is suitable and effective in testing hypotheses on specific experiences such as attending classes.

4.3.1 Clinical Interview

Clinical interview is one of the most popular techniques in science and mathematics education. Derived from the original works of Piaget, clinical interview is widely used to explore the cognitive structure of the interviewee's knowledge (Osborne & Gilbert, 1980; Pines, Novak, Posner & Vankirk, 1978; Posner & Gertzog, 1982; Sutton, 1980 and; West & Pines, 1985). In a clinical interview, the interviewer must be an expert in the topic of discussion. The interviewer asks the interviewee a set of problems on a particular topic in order to probe what is in the interviewee's mind. Clinical interview provides a flexible and non-standardized technique for investigating the interviewee's thinking of specific concepts in science. This technique is "directed toward the information-gathering function" (Posner & Gertzog, 1982, p.195) as it allows the interviewer to talk freely with the interviewee, "yet probing to check the basis of his reasoning" (Sutton, 1980, p. 109).

In a clinical interview, the interviewee dominates the interview conversation (Posner & Gertzog, 1982). The interviewer interprets the answer and continues the discussion by using probing questions, which aim to obtain rich and in-depth information. The main intention in clinical interviews is to draw a conclusion about the interviewee's understanding regarding specific concepts. As stated by Posner and Gertzog (1982), clinical interview is one of the important measurements in determining a student's conceptual change. They highlighted that:

> The method [clinical interview] is highly flexible, allowing a skillful researcher both to probe the areas of the knowledge domain of particular interest and to let the subject speak freely, while constantly checking his/her spontaneous remarks for those that will prove genuinely revealing....Two techniques may be employed, a controlled but flexible conversational interview, and an interview centered around a contrived task designed to reveal the nature of certain aspect of the subject's intelligence (Posner & Gertzog, 1982, p. 197).

4.3.2 Interview-About-Instance (IAI) and Interview-About-Event (IAE)

The IAI interview is used primarily to explore students' understanding of a particular science concept (Osborne & Freyberg, 1985). Its process involves the interviewee being shown a series of pictures, followed by probing questions to investigate his/her understanding of a specific concept shown earlier. For example, Osborne and Freyberg, (1985) designed IAI cards to illustrate situations with criterial and non-criterial attributes of plants. For the current study, the representation of instances was derived from illustrations and chemical formulas given by the interviewee, and not from the interviewer. However, the interviewer used these illustrations or chemical formulas to generate follow-up questions to probe interviewee's understanding.

As stated by Hickey (1997), IAI allows the interviewer to use strategies such as questioning for clarification, extension or repetition in order to verify the interviewee's understandings and to get clearer explanations. In this case, the interviewer does not introduce or mention any terminology or term, which can assist in the answer of the question unless the terminology or term is first mentioned by the interviewee.

IAE is an interview technique similar to IAI, but it gives more focus on scientific events or changes, instead of scientific instances. For IAE, the interviewee observes events such as lighting a candle and describes the science concepts involved. For example, Osborne and Freyberg (1985) used a set of cards regarding light to explore the interviewee's ideas concerning light such as emission, reflection and absorption. In IAE, the interviewee is asked to describe what happens in the scientific events or phenomena. The interviewer then invites the interviewee to describe the terminology or concept used in describing these events or phenomena.

By combining semi-structured and unstructured questions in clinical interviews, the IAI and IAE techniques give more flexible design, whereby their main function is to "focus attention on a given experience and its effects" on the interviewees (Kidder & Judd, 1986, p.274). These types of interviews allow flexibility for the interviewer to focus and direct the flow of interview on specific knowledge content of electrochemistry.

4.3.3 Pilot Study

A pilot study for the interview was conducted on a group of six students who did not participate in the actual interviews. Other than to ascertain the suitability of the pre-structured interview questions, the pilot also serves to familiarize the researcher with the interview setting. This is one of the main steps suggested by Silverman (1993) in order to establish the reliability of the interview. In addition, Burn (1998, p. 334) noted that the pilot interview "need[s] to be as close in context to the realities of the actual studies as possible." Following his suggestion, a two-step guideline was used. The procedure is as below:

Step 1: Ask factual questions derived from the interviewee's pre-test and post-test written answers. For example 'Referring to your answer in Question 2, which one is a reducing agent?

Step 2: Ask direct follow-up and probing questions based on the interviewee's responses. For examples, 'Can you explain why you think that Zn^{2+} is a reducing agent, not Zn?'

Finally, the pilot study revealed that the students had no problem answering the pre-test and post-test questions in English because all tests and examinations at the centre were conducted in English. However, it was found that the students who participated in the pilot study had trouble giving verbal explanations in English during the interview. Most felt more comfortable expressing their opinions in Malay, their native language. As pointed out by Kozma and Russell (1997), most students find it difficult to spontaneously express their ideas of scientific concepts in an accurate scientific statement verbally as compared to written answers because they are not trained to do so. Therefore, the actual interviews were conducted in the Malay language, even though the answers written in the pre-test and post-test were English.

4.3.4 Interviews in the Study

Interviews in this study were used to gather data on the interviewee's explanations of general and specific questions in the pre-test and post-test about electrochemistry, measured over four general and five specific concepts. Examples of general concepts are:

1. definition of oxidation and reduction,
2. identification of reducing and oxidizing agents,
3. explanation of how an electrolyte conducts electrical current,
4. explanation of why the cathode could be negatively or positively charged, and
5. prediction of anode and cathode for electrochemical cells.

Examples of specific concepts involving both electrolytic and galvanic cells are as follows:

1. The reactions occurring at the anode and cathode in electrolytic cell.
2. The electroplating process.
3. The reactions occurring at the anode and cathode in a galvanic cell.
4. The function of a salt bridge.

The interviews were conducted in seven stages. These stages were as follows:

1. Introduction.
2. Asking interviewee to introduce himself/herself.
3. Outlining the purpose of the interview.
4. Asking permission to record the conversation.
5. Conducting the interview session.

6. Expressing appreciation to the interviewee.

In this study, no fixed questions were prepared prior to the interview. In fact, the questions asked were dependent on each interviewee's responses to the earlier written tests. Each interview took approximately 40 minutes. The interview was audio-taped and then transcribed by the interviewer as soon as possible, as suggested by Osborne and Freyberg (1985). Immediate transcription allowed the interviewer to improve the technique of asking questions for the next interview. Subsequently, the transcripts were translated into English by the researcher for data analysis. However, to maintain the authentic tone of the original interviews, the translation used the English normally spoken in the Malaysian classroom.

During each interview, the interviewee was asked to verbalize his/her answer and asked to illustrate explanations using diagrams or chemical equations. These illustrations may have provided extra information about the interviewee's current understanding, developed from their existing knowledge. Finally, it was anticipated that the combination of the interviewees' responses from the interview with their written answers in the pre-test and post-test would provide some insight into the interviewees' conceptual change.

4.3.5 Validity and Reliability

Several steps were taken to establish the validity and the reliability of the interview. Three specific steps were taken to ensure valid and reliable research findings.

Firstly, as mentioned earlier, the interview was piloted prior to the actual study. The questions asked mostly depended on the interviewee's written answers and responses, thus adding to the validity of the interview. Secondly, the possible bias of the interviewer (for example a tendency to seek answers that support his/her hypotheses) and the content of the questions (for example a tendency to ask leading questions), as highlighted by Cohen et al. (2000), were kept to a minimum by the conversation being focused on the interviewee's responses and how he/she answered the pre-test and post-test questions. Thirdly, the interview transcripts were later cross-checked with data from written pre-test and post-test answers, again strengthening the validity and reliability of the interview.

Other than the steps mentioned above, data triangulation was used to ensure the validity and reliability in data analysis. Data triangulation was used to overcome the weaknesses and bias created from the use of a single method of data collection and to provide a more meaningful explanation of complex phenomena (Cohen et al., 2001). For this study, the use of different methods on the same subjects, or between methods' triangulation (Denzin, 1990), was carried out by comparing and integrating data collected during the interview with data obtained from the pre-test and post-test. Furthermore, the questions dealt directly with the interviewees' own answers in the pre-test and post-test. This kept the conversations focused and straight forward.

4.3.6 Interview Settings

The interviews were held in an administrative meeting room, the Matriculation Center, International Islamic University, Malaysia. The interviewees did not take long to come for their interview sessions, as the venue is located near the students' hostels and other academic buildings. The meeting room was selected for the interview because it was comfortable and familiar to the interviewees. Interview procedures were employed in an informal manner in order to create a relaxed atmosphere. All appointments with the interviewees were arranged through their mobile phones.

4.4 Sampling Procedure

The subjects consisted of 60 high achiever students and 60 low achiever students, as described in detail in the Part III (Section 3.1.3). For the interview, six subjects were purposely selected from the CAnI and the CBI groups. Three subjects were selected from each group. The selected subjects were then called interviewees. Interviewees were anonymous to preserve their confidentiality and anonymity (Berg, 2001) and only identified here by pseudonyms.

This purposeful sampling, also known as judgmental sampling (Berg, 2001), allows researchers to select a specific sample of subjects within a certain criterion. According to Patton (1990), purposeful sampling typically focuses on relatively small purposely-selected subjects. Cohen et al. (2000) highlighted that the selection of subjects for purposeful sampling should be based on specific characteristics, which at the same time are relevant to the objective of the study. Wiersma (1995, p. 301) further mentioned that an advantage of purposeful sampling is that it can be used in order "to obtain information-rich units in the sample".

Based on the above understanding, the three subjects from each group who obtained the highest gained score between pre-test and post-test were selected as shown in Table 39.

Table 39

Subjects for interviews

Group	Pseudonyms
CBI	Annie
	Anna
	Amy
CAnI	Sally
	Sofia
	Sarah

This was done on the rationale that those who obtained the highest gained score are more likely to have experienced conceptual change and be a source of rich information during the interviews. According to Patton (1990), the number of subjects required is dependent on what the researcher wants to discover. It is believed that the six subjects selected would provide in-depth information to the focus of the study. Moreover, the selected subjects can be considered a reference group of key informants, who can provide valuable information in the understanding of conceptual change process.

4.5 Procedures

The whole study was conducted in four sessions. In session 1, the pre-test was administered to both the CAnI and the CBI groups, followed by four unit lessons on electrochemistry in session 2. In session 3, the post-test was administered. The post-test answers were used to identify the conceptual change after treatment. This was followed by a questionnaire session. The questionnaire took approximately 20 minutes to complete. The students were asked to complete open-ended questions in order to obtain their perceptions towards CAnI and CBI, respectively. The last session was session 4, the interview session.

The interviews were conducted on a one-to-one basis. Each interview lasted between 40 and 60 minutes. The interview sessions started with factual questions based on the interviewee's pre-test and post-test written answers followed by in-depth probing questions. The interviewee was asked to give clear answers but no attempt was made to guide the interviewees toward obtaining the correct answers.

Each conversation was recorded using a tape recorder. The tapes were afterwards transcribed for analysis. Interviewees not only verbalized their thinking regarding electrochemistry concepts, but also drew their models of electrochemical cells on a piece of paper. Each interviewee was given a special blank form on which he/she could draw any illustration or chemical formulation during the interview. Hence, the transcript was a result of the joint recorded verbal data during the interview and the information written in the form given to the interviewee during the interview. An example of part of the interview transcript is shown in Figure 22.

Group: CAnI
Interviewee: Sarah (Pseudonym)
Date: 22 December 2004, 2.00 pm

Artifacts of transcription:
Underline: Emphasis key words
[ ] : Comments inserted by researcher to clarify the discourse
.... : Pause / silent

Researcher: What did you mean that oxidation is a process when electrons are released?

Sarah: Yes...it is a process to release electron...

Researcher: What did you mean that cathode is receiving the anion?

Sarah: I'm guessing the answer.

Researcher: Rewrite the equation for this question.

Sarah: [Writes equation 1]

$$Zn + Cu^{2+} \rightarrow Zn^{2+} + Cu \qquad \text{(Equation 1)}$$

Researcher: How do you identify a reducing agent?

Sarah: Reducing agent...undergoes the oxidation process.

Researcher: So, which one is the reactant which undergo oxidation?

Sarah: The reactant, which releases electrons...

Figure 22. Example of part of interview transcript.

4.6 Results and Discussion

Qualitative data analysis in this study was carried out on the students' perceptions toward CAnI and CBI. Data in the form of interview transcripts combined with the pre-test and post-test written answers, were gathered from face-to-face interviews between the researcher and students.

4.6.1 Open-ended Questionnaire

The open-ended questions consisted of short answer questions, which allowed the subjects to write free responses and personal comments in their own words. These responses were used to obtain students' perceptions towards CAnI and CBI. Responses with similar meanings were classified and expressed in terms of frequency and percentage of responses. No response and irrelevant responses were classified under 'Not applicable' and were omitted from the discussion. Table 40 shows examples of responses being classified.

Table 40

Classification of Responses

Examples of Responses	Response Classification
"It makes me better understand by using animations" "By using transparencies, it is more systematic and easy to understand"	Easy to understand
"I can imagine how the cell works" "I could see the electron's movement"	Able to imagine the phenomena / processes
"Makes jokes" [No responses] or "No comment"	Not applicable

Table 41 presents the responses for each question in the open-ended questionnaire, expressed in terms of frequency (Freq.) and its percentage (%) of the total number of responses for both groups in descending order. Only the most frequent responses and responses that were not redundant were analyzed.

Table 41

Students' responses to the open-ended questionnaires

Question 1	Response Classification	Freq	%
CBI Group:	▪ Easy to understand	18	32.7
Identify one or two things that	▪ Clear presentation	18	32.7
you liked about the teachers'	▪ Able to imagine chemical processes	2	3.6
presentation using	▪ Interesting	1	1.8
transparencies and why?	▪ Easy to remember the contents	1	1.8
	▪ [Not applicable]	15	27.3
CAnI Group:	▪ Easy to understand	18	29.5
Identify one or two things that	▪ Able to imagine chemical processes	16	26.2
you liked about the teachers'	▪ Clear presentation	13	21.3
presentation using animations	▪ Interesting	11	18.0
and why?	▪ Easy to remember the contents	3	4.9
	▪ [Not applicable]	6	9.8

Question 2	Response Classification	Freq	%
CBI Group:	▪ Teacher's explanation was too fast	18	38.3
Identify one or two things that	▪ Not interesting	8	17.0
gave you problems in	▪ Difficult to understand/confusing	7	14.9
understanding the teacher's	▪ Unable to imagine chemical processes	6	12.8
presentation and why?	▪ [Not applicable]	8	17.0
		7	17.5
CAnI Group:	▪ Teacher's explanation was too fast	4	10.0
Identify one or two things that	▪ Difficult to understand/confusing	2	5.0
gave you problems in	▪ Not interesting	0	0.0
understanding the teacher's	▪ Unable to imagine chemical processes	27	67.5
presentation and why?	[Not applicable]		

Table 41 (continued)

Question 3	Response Classification	Freq	%
CBI Group:	▪ Clear explanation	14	31.8
What aspects of the teacher's	▪ Gave clue to memorizing	7	15.9
presentation have been the	▪ Illustrations are interesting	1	2.3
most helpful in improving	▪ Able to imagine chemical processes	0	0.0
your understanding of	▪ Easy to understand	0	0.0
electrochemistry concepts?	Examples:		
Please explain by giving at	▪ Memorize the Electrochemical Series	2	4.5
least two examples.	▪ Spoke clearly / loudly	2	4.5
	▪ Gave specific example of concept	2	4.5
	▪ [Not applicable]	16	36.4
CAnI Group:	▪ Animations were interesting	12	26.7
What aspects of the teacher's	▪ Easy to understand	9	20.0
presentation have been the	▪ Clear explanation	2	4.4
most helpful in improving	▪ Able to imagine chemical processes	2	4.4
your understanding of	▪ Gave clues to memorizing	0	0.0
electrochemistry concepts?	Examples:		
Please explain by giving at	▪ Memorize the Electrochemical Series	0	0.0
least two examples.	▪ Spoke clearly / loudly	0	0.0
	▪ One specific example of each concept	12	26.7
	▪ [Not applicable]	8	17.7

Question 4	Response Classification	Freq	%
CBI Group:	▪ Provide better explanation	10	21.3
Please give at least one	▪ More illustrations	8	17.0
suggestion of how you think	▪ More examples	4	8.5
that the teacher's presentation	▪ More discussion with students	2	4.3
by using transparencies (and	Special features:		
whiteboard) can be improved.	▪ Use colorful transparencies / pens	14	29.8
	▪ Bigger font size		
	▪ [Not applicable]	3	6.4
		6	12.8

Table 41 (continued)

Question 4	Response Classification	Freq	%
CAnI Group:	▪ Provide better explanation	5	11.6
Please give at least one	▪ More animations	3	7.0
suggestion of how you think	▪ More examples	2	4.6
that the teacher's animations	▪ More discussion with students	1	2.3
can be improved.	Special features:		
	▪ Use sound effects	10	23.2
	▪ Insert cartoons	4	9.3
	▪ Insert video clips	1	2.3
	▪ Insert real pictures	1	2.3
	▪ [Not applicable]	16	37.2

Question 1:

CBI Group. 32.7% of the respondents perceived that the use of transparencies was 'easy to understand' as well as providing 'clear presentation.' This might relate to the clear graphic illustrations of the transparencies, which were earlier prepared using computer drawing tools. The results also revealed that only a small number of responses (3.6%) claimed the use of still graphic illustrations in the teacher's presentation helped them imagine chemical processes whilst a very small percentage (1.8%) claimed that the use of transparencies made the teaching process interesting and the recall of content easier.

The results were consistent with a study conducted by Iwanski (2000), which supported the belief that transparencies were not interesting for the majority of students as a method of delivering learning materials, and contributed to student boredom compared to computer-mediated instruction. When a static illustration with a lot of information was printed on a single page of the transparency, it was difficult for students to grasp abstract concepts, especially at the molecular level of presentation. Moreover, transparencies that portrayed static chemical phenomena might fail to draw the subjects' attention to the concepts being taught.

CAnI Group. A relatively higher percentage of students in the CAnI group perceived that animations were not only 'easy to understand' (29.5%) and provided 'clear presentation' (21.3%), but were also 'interesting' (18.0%), 'easy to remember' (4.9%) and therefore, easier for students to 'imagine chemical processes' (26.2%). This result is supported by that carried out by Greenbowe (1994) who suggested that animations could be used as an effective tool in presenting complex, abstract and dynamic chemical processes. Burke et al. (1998) added that animations have the ability to facilitate the construction of knowledge by communicating abstract conceptual processes to students at a microscopic level of presentation. At the same time, animation could also increase the students' focus and curiosity to learn (Iwanski, 2000).

Question 2:

CBI Group. When asked to identify one or two things that were problematic in understanding the teacher's presentation, nearly 40% of the respondents indicated that the use of transparencies made the teaching process even faster as the teacher explained a large amount of information in one single transparency with texts, diagrams, and chemical equations. This can be understood as being due to the teacher tending to explain a large amount of information in a relatively short time using static illustration on transparencies containing many facts and concepts at the symbolic, macroscopic and microscopic levels. Some of the students agreed that the use of transparencies was not interesting (17.0%), difficult to understand (14.9%) and unimaginable (12.8%) in the teaching of chemical phenomena.

CAnI Group. When asked to identify one or two things that were problematic in understanding the teacher's presentation using animations, the results revealed that some students thought the teaching process was too fast (17.5%), difficult to understand (10.0%) and not interesting (5.0%). Interestingly, none of the respondents claimed that they were unable to imagine chemical phenomena from the teacher's presentation using animations. Note that previous studies (Garnett & Treagust, 1992; Huddle & Margaret, 2000; Ozkaya, 2002; Sanger & Greenbowe, 1997a, 1997b, 1999) have all found that electrochemistry is perceived by students as a difficult topic regardless of the method of instruction. This is usually explained as being due to the difficulty to explain dynamic and abstract concepts at the molecular level of presentation. Overall, it seems that the use of animation is a more effective approach at conveying concepts at the molecular level for a majority of subjects in the CAnI group.

Question 3:

CBI group. For this question, respondents stated that clear explanation (31.8%) was one of the most helpful aspects of the teacher's presentation using transparencies in improving understanding of electrochemistry concepts. Another aspect was the use of simplifications of facts (15.9%) such as memorizing the Electrochemistry Series (4.5%). Perhaps the teacher in the CBI group utilized this direct transmission approach that merely emphasized explaining statements of concepts as written in textbooks. Sanger and Greenbowe (1999) agreed that most chemistry textbooks illustrate the sequence of the chemical processes through the simplifications of facts or simple arguments.

These results were consistent with Zin's and Lewin's (1993) results which showed that students prefer subject contents in simplified forms. Despite the students' preferences for simplified content, teachers need to understand that by simplifying difficult concepts like electrolysis, students' conceptual understanding may not improve.

CAnI group. Respondents claimed that the animation presentation was one of the most helpful aspects of the teacher's presentation regarding improving understanding of electrochemistry concepts (26.7%) and the animation presentation was easy to understand (20%). These results support the fact that the integration of animations in chemistry lessons provides meaningful representations, particularly highlighting the connections between and amongst microscopic, macroscopic and symbolic levels (Burke et al., 1998). Furthermore, the respondents claimed that giving specific examples of concepts (26.7%) contributed to the improvement of the students' understanding. This relatively higher percentage showed that animations were better at conveying accurate depictions of concepts, rich for uptake, thereby providing students in the CAnI group opportunities to mesh the specific concept meaningfully with deeper understanding.

Question 4:

CBI group. Subjects suggested that the teacher's presentation could be improved through better explanation (21.3%) and through the provision of more illustrations (17.0%). This may be related to the previous responses that claimed the use of transparencies made lessons on chemical processes difficult to understand as well as hard to imagine, hence the need for students to depend on teacher's verbal explanation. The responses suggested that the use of colorful transparencies (29.8%) with attractive illustrations could further improve the teacher's presentation. Compared to 'black and white' illustrations, colored illustrations printed on transparencies would provide not only clearer visual learning materials, but also simultaneously sustain the students' focus and attention on the material.

CAnI Group. The most frequent responses were that the teacher's presentation could be improved by giving better explanation (11.6%) and providing more animations (7.0%). Only a small percentage of responses suggested that the explanation from the teacher along with the exposure to animations was not quite adequate for them to grasp the fundamental concepts offered. It seems there were a minority of students in the CAnI group who found electrochemistry difficult to learn even through animation. The responses suggested the addition of multimedia features such as sound effects (23.2%) to create better animations and to attract students' attention. The benefits of added multimedia features have earlier been highlighted in the work of Allendoefer (2003). He mentioned that adding multimedia features such as sound effects was a good idea if inserted necessarily.

4.6.2 Interview

In addition to open-ended questionnaires, interviews were also carried out with the intention of dominating the subjects' specific conceptual change. In order to do this, the written transcripts and the pre-test and post-test answers were analyzed to identify statements, which can be linked to the students' conceptual change. Six subjects, three each from the CAnI and CBI groups were purposively selected.

The interview transcripts were analyzed individually to examine the possible process of conceptual change. Full transcripts are shown in Appendix I. Specifically, the researcher was interested to find out how strongly or weakly conceptual change took place as a result of different teaching approaches. Weak conceptual change involves the addition of new knowledge without the involvement or changing of students' existing ideas. For this addition of information, students' overall patterns of existing ideas are not restructured, but their applicability is extended. Strong conceptual change, on the other hand, involves the revision or restructuring of students' overall pattern of existing ideas. Here, conceptual change is the result of assimilation as well as accommodation, generating the ability to restructure and apply knowledge in different contexts.

4.6.2.1 Scores gained by Interviewees

Based on the operational definition for this study, initial evidence of conceptual change was obtained from the difference between the pre-test and post-test scores of the individual interviewees, which reflected the development of knowledge during the instructions. Tables 42 and 43 show scores by the three interviewees from each group who obtained the highest gained score between the pre-test and post-test. However, since the score gained by interviewees was not part of the study's research questions, the discussion that followed will not be in detail.

Table 42

Scores by individual subjects interviewed (CBI Group)

Section A		**Annie**		**Anna**		**Amy**	
Question	**Full Marks**	**Pre-test**	**Post-test**	**Pre-test**	**Post-test**	**Pre-test**	**Post-test**
1	2	0	2	0	2	1	1
2	1	1	1	0.5	0.5	0.5	0.5
3	3	0	1	0	2	0	1
4	2	0	2	0	0	0	0
5	2	0	2	0	2	0	2
Total A	10	1	8	0.5	6.5	1.5	4.5
Section B		**Annie**		**Anna**		**Amy**	
Question	**Full Marks**	**Pre-test**	**Post-test**	**Pre-test**	**Post-test**	**Pre-test**	**Post-test**
1	8	0	3	0	1	4	6
2	7	0	2	2	5	0	6
Total B	15	0	5	2	6	4	12
Total A + B	25	1	13	2.5	12.5	5.5	16.5
Gained Score: (Post -Pre)		**12**		**10**		**11**	
Total Gained Score = 32							

Table 43

Scores by individual subjects interviewed (CAnI Group)

Section A		**Sarah**		**Sally**		**Sofia**	
Question	**Full Marks**	**Pre-test**	**Post-test**	**Pre-test**	**Post-test**	**Pre-test**	**Post-test**
1	2	0	2	0	2	1	2
2	1	0.5	1	0	1	0.5	1
3	3	0	2	1	1	1	1
4	2	0	2	0	2	0	1
5	2	0.5	2	1	2	0	2
Total A	10	1	9	2	8	2.5	7
Section B		**Sarah**		**Sally**		**Sofia**	
Question	**Full Marks**	**Pre-test**	**Post-test**	**Pre-test**	**Post-test**	**Pre-test**	**Post-test**
1	8	1	7	0	7	0	5
2	7	2	2	0	4	0	4
Total B	15	3	9	0	11	0	9
Total A + B	25	3.5	18	2	19	2.5	16
Scores Gained: (Post – Pre)		**14.5**		**17**		**13.5**	
Total Gained Scores = 45							

Tables 42 and 43 show the actual scores by three subjects from each group who obtained the highest gained score between pre-test and post-test. The scores gained by each of the interviewees in the CAnI group (Sarah = 14.5, Sally = 17, Sofia = 13.5) were greater than those gained by the CBI subjects (Annie = 12, Anna = 10, Amy = 11). The scores of the three subjects from the CAnI groups were also substantially higher than those of the CBI group, a total of 45 marks against 32 marks.

4.6.2.2 Analysis of Conceptual Change

The interviewees' written answers and interview transcripts were analyzed qualitatively with respect to their:

1. ideas before instruction;
2. misconceptions before and after instruction;
3. scientific conceptions before and after instruction; and
4. recognition of cognitive conflict.

The four indicators were interrelated with each other and were used to determine the interviewees' conceptual change. However, only responses of interviewees who provided relevant indicators of conceptual change were highlighted in describing the findings of the study.

Section A - Question 1

Pre-test question:

Define (a) Oxidation (by electron transfer) (b) Anode

Post-test question:

Define (a) Reduction (by electron transfer) (b) Cathode

Question 1 was designed to probe the subjects' understanding of factual knowledge in the form of concept definitions in electrochemistry based on objectives a, b, e, and f of the lesson plan (Unit 1, Appendix A). The relevant concepts of interest are: oxidation, reduction, cathode and anode in terms of electron transfer. Accordingly, subjects should be able to identify and define the combination of oxidation-reduction and anode-cathode.

In this question, the expected response for the definition of oxidation is 'a process in which electrons are donated by a species. In contrast, reduction is 'a process in which electrons are gained by a species.' In any electrochemical cell, the anode is the electrode at which oxidation occurs while the cathode is the electrode at which reduction occurs.

CBI Group: Annie, Anna and Amy

In the pre-test, only Amy was able to write the correct answer for the definition of oxidation. She remembered what was taught to her during her secondary education. When asked how she knew the answers, Amy's reply was as follows:

Researcher: How did you know that oxidation is a process that release electrons?

Amy: I have learnt it in form 4 [secondary school].

Researcher: What about cathode?

Amy: Yes...that too.

The above response showed that Amy remembered the factual knowledge about oxidation and so it was a part of her existing electrochemistry knowledge. However, her definition of cathode was wrong. She mistakenly wrote in the pre-test that cathode was 'the negative electrode that attract positive ions', indicating that Amy held a misconception. It is correct to say that a 'negative electrode attracts positive ions.' However, the answer is wrong in the sense that cathode is not 'a negative electrode' by definition but 'an electrode at which reduction occurs.'

Meanwhile, Annie and Anna had some ideas about oxidation but confused the definitions of oxidation and reduction, even though such definitions are a foundation in understanding electrochemistry. Surprisingly they had gone through the definitions when they were in secondary school. For example, Anna defined oxidation as 'gain electron'. Perhaps she knew that oxidation is something to do with 'electron movement' not linked to the exact process at the molecular level. The definition is actually correct for reduction, not oxidation. This revealed that Annie and Anna had difficulty defining oxidation and reduction.

For the next question in the pre-test, all interviewees seemed unable to give correct definitions of cathode. Annie and Anna associated cathode with 'something negative'. For example, Annie defined cathode as "an electrode, which attract electron" and Anna defined it as a "negative pole". In response to a question designed to probe her understanding of cathode, Anna said:

Researcher: **Why did you choose cathode as the negative pole?**

Anna: **I thought that the cathode is <u>negative</u> and the anode is positive.**

Anna simply believed if 'cathode is negative' so 'anode is positive'. This response revealed a partial understanding and appears to be a common misconception among students in previous studies (see Garnett & Treagust, 1992; Huddle & Margaret, 2000; Ozkaya, 2002; Sanger & Greenbowe, 1997a).

Annie's and Anna's responses to the definition of cathode were typical examples of incorrect existing knowledge or misconception, which seems to be a common phenomenon amongst students. To justify her answer, Anna immediately said, "anode is positive." Such statements are common amongst chemistry students. Table 2 documented from previous studies two common student misconceptions, 'the anode is positively charged because it has lost electrons; the cathode is negatively charged because it has gained electrons'. These answers might be true for the electrolytic cell because the cathode receives electrons from the batteries (or any electrical source) and becomes negatively charged. In contrast, the cathode in the galvanic cell is positively charged because it releases electrons to cations. The interviewees showed uncertainty about the assignment of electrodes as positive or negative terminals in the galvanic cell. This is an example of a misconception for cathode and anode, which may inhibit the understanding of future knowledge of electrochemistry.

In the post-test, the definition of reduction was asked instead of oxidation. Annie, Anna and Amy had no difficulty giving correct answers. All of them defined reduction as a process of gaining electrons. For example, Anna wrote "reduction occurs when gaining e [electron]". This suggests that at this level, Annie, Anna and Amy possessed factual knowledge of reduction after receiving electrochemistry instruction.

For the next question in the post-test, Annie and Anna were able to give the correct answers. Annie for example, wrote that anode "is the electrode where the oxidation occurs." Both students rationally accepted the new definition of oxidation-reduction and anode-cathode. Amy, who had no idea about cathode in the pre-test, responded incorrectly during the post-test. She also wrongly indicated anode as "the positive electrode that attracts negative ions." She was not aware of her misconception and when asked:

Researcher:	**What made you choose the anode as the positive electrode?**
Amy:	**I just exchanged it with the cathode....because the cathode is negative.**

Amy's response established her misconception that the cathode is negative. This belief is obviously repeated in the post-test when she answered "anode is positive" which reflected her partial understanding of the concept of cathode-anode. It can be seen here that Amy still held the misconception regarding the definitions of an anode and a cathode despite receiving the electrochemistry instruction, supporting a previous study by Swaak and de Jong (2001). He stated that some misconceptions are highly resistant to change especially when the students believe that their ideas are intelligible and provide satisfactory interpretations to them. Consequently, incorrect or partial understanding of one concept may lead to the other misconception of another related concept.

CAnI Group: Sarah, Sally and Sofia

In the pre-test, only Sofia wrote the correct answer for the definition of oxidation. She stated that oxidation is "release the electrons to increase the oxidation number". When asked how she knew the answer:

Researcher:	**Based on your pre-test answer, how do you know that 'oxidation is a process of releasing electrons'?**
Sofia:	**I still remember the definition.**

Sofia claimed that she recalled the definition of anode during previous formal instruction. Although some aspects of science require memorization of fundamental facts, it can be considered rote learning if the information is purely memorized without understanding.

Meanwhile, Sally defined oxidation as a "process of gain[ing] electrons" while Sarah had no idea about oxidation at all. These answers suggest that there were students who memorized the relationship between oxidation-reduction with the process of releasing-gaining electrons. That is why some of them were lucky enough to get the correct combination (oxidation-releasing electrons or reduction-gaining electrons).

For the second pre-test question, Sarah, Sally and Sofia failed to define cathode. They defined cathode as "receive the anion", "the negative terminal" and "receive anion" respectively. The following are Sarah's, Sally's and Sofia's responses when further asked about the definition of cathode.

Sarah's response:

Researcher: What do you mean that cathode is receiving the anion?
Sarah: Because cathode is <u>negative</u>...

Sally's response:
Researcher: What about cathode?
Sally: Initially I thought the cathode was <u>negative</u>...I thought the answer was correct.

Sofia's response:
Researcher: What do you mean by cathode is a process of receiving anion?

Sofia: I'm sure that cathode receives anion...

Such responses reflect that Sarah, Sally and Sofia held misconceptions when they associated cathode with 'something negative' (terminal or ions) even though it is obvious that the statement given by Sofia that "cathode attracts anion" contradicted with scientific logic that anions (negative ions) move away from a negatively charged electrode. Sofia in this case, failed to reconcile her misconceptions and seemed to ignore her potential cognitive conflict state by accepting that "cathode receives anion." In this sense, there was evidence that Sarah, Sally and Sofia possessed a lack of knowledge about cathode and anion. Indeed, Sarah and Sally might have thought that anions have a positive charge. These misconceptions are also common and consistently held by students in Taiwan (Lin et al., 2002).

In the post-test, Sarah, Sally and Sofia gave the correct definition of reduction. They defined reduction as a process of gaining electrons. For Sally, reduction is a "process of accept[ing] electrons in chemical reactions". This revealed that all of them were able to grasp the definition of reduction after receiving the electrochemistry instruction.

For the second question of the post-test, Sarah, Sally and Sofia were able to give the correct definition for anode. For Sarah and Sofia, anode is a terminal at which oxidation occurs while for Sally, anode is a terminal at which the electrons are released. Nothing much can be said regarding the conceptual change at this level, because one cannot tell from these answers whether students are recounting memorized facts, or showing the 'tip' of their rich conceptual understanding.

In summary, the analysis of pre-test answers showed that subjects in both CAnI and CBI groups possessed some kind of existing knowledge which associates cathode as a negative electrode or that the cathode is negatively charged. This knowledge was almost certainly acquired during formal chemistry instruction when they were in secondary school. When asked to elaborate further, they failed to justify their answers. The subjects in both groups tended to extend what they could understand or remember as an electrolysis process to all electrochemical cell discussions.

Only one the subjects from the CBI group (Amy) had the tendency to maintain her assumption that the cathode is negative in the post-test even after attending formal instruction. Although this assumption is partially correct (only applicable to electrolytic cell), it can lead to other misconceptions. Finally, based on the overall post-test answers, it is suggested that subjects in both groups experienced weak conceptual change as they failed to connect the structure of the concepts meaningfully.

Section A - Question 2

Choose the reducing agent and oxidizing agent in the following reaction:

$$Zn + Cu^{2+} \longrightarrow Zn^{2+} + Cu$$

(i) Reducing agent is ______ (ii) Oxidizing agent is ______

The above question was designed to probe the extension of the interviewee's understanding about oxidation and reduction based on the objectives d, e, and f of the lesson plan (Unit 1, Appendix A). By definition, a reducing agent is a species that 'reduces another substance', 'is reduced' or 'gain electrons.' In contrast, an oxidizing agent is a species that 'oxidizes another substance', 'is oxidized' or 'loses electrons.' This can be easily tracked using three possible sequences of the conceptual set as follows:

Zn (reactant): Lost electrons ⟷ Oxidation ⟷ Reducing agent

Cu^{2+} (reactant): Gained electrons ⟷ Reduction ⟷ Oxidizing agent

CBI Group: Annie, Anna and Amy

For the pre-test, Annie rightly determined the reducing and oxidizing agents, Zn and Cu^{2+} respectively. Anna and Amy, however, chose Zn and Cu as the answers for the question. Surprisingly, they gave the same answers in the post-test.

Annie's responses:

Researcher: How did you know that Zn is a reducing agent?

Annie: Zinc releases electrons to form zinc ion, therefore <u>zinc</u> is the reducing agent.

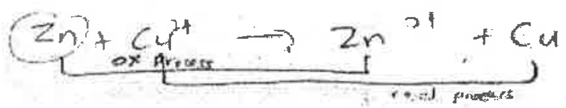
Researcher: What about the oxidizing agent?

Annie: It gains electrons....so <u>copper ion</u> is the oxidizing agent.

Anna's responses:

Researcher: Rewrite the equation.

Anna: [Writes Equation 1]



Equation 1

Researcher: Which is the reducing agent?

Anna: The reducing agent is <u>Zn</u> .

Researcher: What about the oxidizing agent?

Anna: It is definitely copper.

Zn is the reducing agent so Cu^{2+} is the oxidizing agent.

Researcher: But why is your answer <u>Cu</u>?

Anna: I didn't know that ion could be a reducing agent.

Amy expressed her answer:

Researcher: Which one is the reducing agent?

Amy: <u>Zinc</u> [refer to equation 2].

Researcher: How do you know that?

reducing agent (↑ Zn)

$$Zn + Cu^{2+} \longrightarrow Zn^{2+} + Cu \qquad \text{Equation 2}$$

Amy: Firstly, I determined which one has been reduced…it is <u>copper</u> [Cu]

Researcher: Can you explain?

Amy: Because the oxidation number has decreased……

Researcher: Please explain.

Amy: Definitely the process of reduction….

Annie used the concept of releasing and gaining electrons to determine the reducing and oxidizing agents. In this case, Annie confidently associated releasing electrons (oxidation) with the reducing agent and gaining electrons (reduction) with the oxidizing agent. However, Anna referred to Zn as the reducing agent because "it reduced others", and then made a conclusion that Cu is the oxidizing agent. Without understanding the role of electron transfer, Anna failed to realize that Cu^{2+} was the one reduced (decrease in oxidation number) not Cu. On the other hand, Amy used oxidation number to determine which species had been reduced and then made a conclusion that Zn is the reducing agent. The way Anna and Amy explained their answers shows that they possessed partial understanding of reducing and oxidizing agents.

Why did Annie correctly choose copper ion as the oxidizing agent but Anna and Amy, though they gave correct explanation, fail to differentiate between copper atom and copper ion? Anna and Amy had difficulties extending their understanding of how to determine whether copper atom, Cu, or copper ion, Cu^{2+} was the oxidizing agent. One possible answer is that Annie used the following conceptual sequence:

Annie: Zn....releases electrons.... reducing agent.

Oxidizing agent.... gains electrons.... Cu^{2+}.

Annie seems to use a correct sequence of concepts. She correctly chose Cu^{2+} because only metal ions (Cu^{2+}), and not metal atoms, can accept electrons (Cu).

However, Anna and Amy used the following conceptual sequences:

Anna: Reducing agent....reduction....Zn

Oxidizing agent....copper

Amy: Reducing agent....Zn...oxidation number increases

Copper has been reduced....copper

Although conceptual sequences used by Anna and Amy seem intelligible, they are incorrect. For example, Anna related the reducing agent to reduction process, which is incorrect. Hence, she failed to justify that chemical reactants could be in atomic form (such as zinc, Zn) or in ionic form (such as copper ion, Cu^{2+}) and that there is actually a pair of redox reaction. Thus, confusions prior to formal instruction remained unchanged and remained exhibited by both of these students in the CBI group.

CAnI Group: Sarah, Sally, Sofia

In the pre-test, Sarah and Sofia wrote Zn and Cu as the reducing and oxidizing agents, respectively. Sally, however, chose Cu^{2+} and Zn as her answers, which were definitely wrong. In the post-test, Sarah, Sofia and Sally all correctly chose Zn as the reducing agent and Cu^{2+} as the oxidizing agent. When describing their answers in the post-test, Sarah, Sally and Sofia made the following responses:

Sarah's responses:

Researcher: **How do you determine a reducing agent?**

Sarah: **A reducing agent…..undergoes the oxidation process.**

Researcher: **So, which one is the reactant which undergoes oxidation?**

Sarah: **The reactant which releases electrons…**

Researcher: **Write down the equation.**

Sarah: **[Writes Equation 3]**

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

Researcher: **The other one.**

Sarah: **[Writes Equation 4]**

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

Researcher: **Please circle the reducing agent.**

Sarah: **Definitely zinc [Zn].**

Researcher: **Which one undergoes reduction reaction?**

Sarah: **Copper ion.**

Sofia's responses:

Researcher: **Which is the reduction agent?**

Sofia: **Zinc.**

Researcher: **How did you know that?**

Sofia: **From the oxidation process.**

Researcher: **Please explain.**

Sofia: **The oxidation number increases.**

Researcher: **What about the oxidizing agent?**

Sofia: **Copper.**

Researcher: **Copper ion or copper atom?**

Sofia: **Copper ion...**

Sally's responses:

Researcher: **Which one is the reducing agent?**

Sally: **Firstly, I noticed .... Cu^{2+} to Cu....it is a reduction**

Researcher: **How did you know it is reduction?**

Sally: **Because...it receives electrons....**

Researcher: **Please explain further.**

Sally: **It [Cu^{2+}] receives electron...**

Researcher: **From which source?**

Sally: **Zinc metal......so the reduction agent is zinc**

Researcher: **What about zinc?**

Sally: **Zinc...oxidation process...copper...reduction agent.**

Researcher: **Which 'copper' do you mean according to your equation?**

Sally: **Cu^{2+}.**

Researcher: **Why is it so?**

Sally: **The reduction of oxidation number.**

Researcher: **Please explain.**

Sally: **The reduction process...so it's an oxidizing agent...**

Sarah, Sally and Sofia explained their answers based on the process of oxidation and reduction. Sarah divided the redox equation into two half equations, indicating that the concepts were intelligible for Sarah. Meanwhile, Sally and

Sofia used the oxidation number to describe their answers. Although the concept of oxidation number was not covered in the instruction, Sally and Sofia could have retrieved it from their existing knowledge. This suggests that when concepts are intelligible, it is easier for students to conceptualize the concepts and link them to existing long-term memory.

In summary, the analysis shows that all subjects in both groups correctly chose 'zinc' as the reducing agent. It seems that the concept was intelligible to the subjects. The difference between the groups is the subjects' selection of oxidizing agent. All three subjects in the CAnI group consistently chose Cu^{2+} or copper ion as the oxidizing agent while two subjects in the CBI group, Anna and Amy, continued to struggle with the idea of correctly determining the oxidizing agent. In this case, they did not refer to the three possible sequences of the conceptual set, but rather used an erroneous relationship between the concepts.

After instruction, the concept of oxidizing and reducing agents appears to be intelligible to the subjects in the CAnI group but not to two of the three subjects in the CBI group. It appears that those subjects in the CAnI group experienced stronger conceptual change compared to the subjects in the CBI group.

Section A - Question 3

Pre-test question:

What allows the molten $PbBr_2$ to conduct electrical current? Describe your answer.

Post-test question:

What allows the aqueous solution of $CuSO_4$ to conduct electrical current? Describe you answer.

Question 3 was designed to probe the extension of the interviewees' understanding about electrolytes and electrolysis based on the objectives i and j of the lesson plan Unit 1 and objective a of the lesson plan Unit 2 (refer to Appendix A). As electrochemistry is chiefly concerned with using or producing electrical current, this application type question is considered crucial in understanding the electrochemistry topic, especially for the understanding of electrolysis process.

To answer this question fully, subjects need to know the definition of electrolyte and the properties of ionic compounds ($PbBr_2$ and $CuSO_4$). Electrolytes such as $PbBr_2$ when in molten state, or $CuSO_4$ when dissolved in water produce free anions and cations. Anions (negative ions) release electrons to cations (positive ions) through the process of oxidation and reduction respectively. In electrolytic and galvanic cells, these ions play the important role of carrying electrical charges to complete the electrical circuit. The transfer of electrons from anions to cations in molten $PbBr_2$ and in aqueous solution of $CuSO_4$ demonstrates the electrical conductivity of these electrolytes.

CBI Group: Annie, Anna and Amy

In the pre-test, only Annie and Anna answered the questions. For Annie, molten $PbBr_2$ conducts electrical current because "in the molten $PbBr_2$, electrons move freely". Meanwhile, Anna gave her response as "...the electron[s] can move to transfer the electrical current". In each of the answers, Annie and Anna tried to construct a logical explanation of the conductivity phenomenon based purely on the existence of free electrons, not on the existence of free ions in the molten, which carry the electrical charges. They believed that the electrons could freely move through molten and aqueous solutions. This implied a lack of deep understanding of what occurs in the electrolyte at the microscopic level.

In the post-test, Annie wrote that $CuSO_4$ aqueous solution conducts electrical current because "there are lots of free ions." This was the answer given in the pre-test. The way she repeated the answer confirmed her partial understanding regarding the role of ions in electrical conductivity through electrolyte. When follow-up questions were asked to obtain in-depth specific information as well as to probe her understanding, Annie changed her answer from 'free ions' to 'free electrons'. However, when confronted with probing questions, she showed evidence of conceptual change. Annie responded as follows:

Researcher: **How did you come up with the answer [regarding electrical conductivity through electrolyte]?**

Annie: **I imagined that the electrons were flowing...but I was not sure where they were moving to...**

Researcher: **Could you write the decomposition equation of $PbBr_2$?**

Annie: **[Writes the equation below]**

$$PbBr_2 \longrightarrow 2Pb^{2+} + Br^-$$

Researcher: **What do you mean by 'the electrons move freely' in molten? Where do the electrons come from?**

Annie: **Bromine is negative.**

Researcher: What is the source of electrons?

Annie: The lead [showing the 2+ sign] …it releases electrons to bromine.

However, when asked further questions, she showed uncertainty about her answers, indicating that she probably experienced a cognitive conflict whilst justifying her answer.

Researcher: Referring to your answer, what is the difference between free ions and free electrons?

Annie: Free ions…

Researcher: Which one is correct?

Annie: I'm confused.

The above response indicated the cognitive conflict experienced by Annie whilst trying to relate the existence of free ions in the electrolyte with electrical current. What was evident and immediately perceivable to her was the erroneous fact that electrons move from lead atom to bromine atom (she did not mention the word 'ion').

Anna wrote that "$CuSO_4$ has free cations and anions that can transfer the electrical current." For Amy, an aqueous solution of $CuSO_4$ conducts electrical current "because of the anions and cations free to move". The answers given by Anna and Amy focused on an aqueous solution consisting of free cations and anions, but omitted a fuller explanation of how these ionic particles carry electrical charges. If Anna believed that electrons flow through the electrolyte independent of the anions and cations, she does not understand the whole process. Anna's and Amy's answers seemed to be consistent with the misconceptions documented by Sanger and Greenbowe (1999) as shown in

Table 2, in particular that "electrons enter the solution from cathode, travel through the solution."

CAnI Group: Sarah, Sally, Sofia

In the pre-test, Sally and Sofia mentioned the existence of cations and anions as being responsible for the electrical conductivity of molten $PbBr_2$, but failed to describe further. Sally wrongly used the terminologies 'positive atom' and 'negative atom' to refer to cation and anion respectively. In fact, there are no positive or negative atoms, because atoms are neutral. This indicates that Sally held some kind of misconception regarding the basic properties of atoms.

In the post-test, Sarah described $CuSO_4$ as an ionic compound, which undergoes "oxidation and reduction to produce electrons." Sofia knew that $CuSO_4$ contains free ions and wrote, "the discharge of the ions produces the electrical current". Sally, in the post-test wrote "anions will release electrons and cations will gain electrons." Sarah and Sally noted the role of anion and cation in the production of electrons in the redox reaction. When asked to describe further Sarah related:

Sarah: **When dissolved, the solution has anions and cations...they have charges.**

Researcher: **Could you elaborate further.**

Sarah: **Oxidation and reduction produce electrons to produce a current.**

Sally, on the other hand, related:

Researcher: **So how does the electrolyte conduct electrical current?**

Sally: **The reaction amongst ions occurred at the anode and the cathode...the positive ions and negative ions moved toward**

	the terminals with opposite charges, so it changed to electrical current…is it correct?
Researcher:	**Can you elaborate further?**
Sally:	**That's all I remember…**

Sofia's responses:

Researcher:	**OK, what do you mean that ions produce electrical current?**
Sofia:	**Because ions have [electrical] charges. These charges produce electrical current.**
Researcher:	**How is it that the electrical current is produced?**
Sofia:	**I'm not sure.**

Although Sofia did not seem confident with her answer, the above responses showed that all subjects in the CAnI group were able to provide an explanation, which was consistent with the scientific view of the concepts. The analysis adds further support the findings that the subjects in the CAnI group experienced stronger conceptual change than the subjects in the CBI group.

In summary, there are similarities in the interviewees' answers for both groups in the pre-test. They used the word 'free' for ionic particles to justify the flow of electrons through the electrolyte even though this idea was not plausible. This appears to be evidence of rote-memorization and misconception (associating electrical conductivity with free electrons) practiced in chemistry instruction. In the post-test, the subjects in the CBI group referred to the existence of ions causing the conductivity of the electrical current but failed to mention that electrons were being transferred by redox reaction activities. None of them described in what way free electrons or free ions were related to the electrical conductivity of the electrolytes. If they knew that free ions could cause electrical conductivity but did not know the concept underlying this process, then it may be concluded that students interviewed from the CBI group experienced only weak conceptual change. In their case, the addition of a specific concept (the existence of free ions) did not incorporate into their existing knowledge. Despite the incompleteness of their answers, none seemed to question the plausibility of their answers.

All the subjects in the CAnI group referred to the conductivity of electrical current as a result of electrical charges carried by ions or as a result of oxidation and reduction processes. The answers given by the CAnI group in the post-test and during interviews showed a dramatic revision of their existing ideas; evidence of their strong conceptual change. In such a manner, it can be suggested that the concepts regarding electrolytic electrical conduction seemed more intelligible and plausible to the students in the CAnI group than the CBI group.

Section A - Question 4

Pre-test question:

Explain why the cathode in an electrolytic cell of molten KCl is negatively charged whilst the cathode in a galvanic cell of Zn-Cu is positively charged?

Post-test question:

Explain why the cathode in an electrolytic cell of molten $PbBr_2$ is negatively charged whilst the cathode in a galvanic cell of Zn-Cu is positively charged?

Question 4 is tricky because it requires a deep understanding of the reactions occurring at the cathodes. This question is difficult to answer because of the dynamic and abstractness of the concepts involved which consist of non-observable phenomena at macroscopic and microscopic levels as well as dynamic motions of molecular particles such as atoms and ions. The above question was designed to probe the interviewees' understanding of 'cathode is an electrode where the process of reduction occurs' based on the objectives c, d, and e of the lesson plan Unit 2 and objective b of the lesson plan Unit 4 (refer to Appendix A).

The question was also designed to confront one of the commonly reported misconceptions held by students (see Huddle & Margaret, 2000; Sanger & Greenbowe, 1997b) that the 'anode is positively charged because it has lost electrons; the cathode is negatively charged because it has gained electrons' as listed in Table 2. Furthermore, it was clear from the analysis of Question 1 and 2 in this study that subjects in both CBI and CAnI groups associated the cathode with negative electrode, not the process of reduction.

This question covers objectives c, d, and e, in lesson plan Unit 2 and objective b in lesson plan Unit 4 (see Appendix A). To answer this question, students need to know that in electrolytic or galvanic cells, the anode is the electrode at which oxidation occurs and the cathode is the electrode at which reduction occurs. In a galvanic cell, the anode is negatively charged and the cathode is positively charged, whilst in an electrolytic cell, the anode is positively charged and the cathode is negatively charged. Students are often confused by this reversal of polarity. These differences can be described as shown in Table 44. The table describes the possible oxidation and reduction half-reactions that occur at the anode and cathode electrodes and the assignment of electrodes as positive (+) or negative (-) in electrolytic and galvanic cells.

Table 44

Anode and cathode in electrolytic and galvanic cells

Electrode (Process)	Electrolytic Cell (molten $PbBr_2$)	Galvanic Cell (Zn-Cu)
Anode (Oxidation)	**Positive (+) electrode**: (electrode carbon has a deficiency of electrons, so it receives electrons from the anode) $2Br^- \longrightarrow Br_2 + 2e$	**Negative (-) electrode**: (zinc: release electrons, which then move towards the cathode) $Zn - 2e \longrightarrow Zn^{2+}$
Cathode (Reduction)	**Negative (-) electrode**: (electrode carbon receives electrons from battery, it has a surplus of electrons, which are donated to the cations, Pb^{2+}) $Pb^{2+} + 2e \longrightarrow Pb$	**Positive (+) electrode**: (electrode Cu has a deficiency of electrons, so it receives electrons from zinc, then the electrons are donated to cations, Cu^{2+}) $Cu^{2+} + 2e \longrightarrow Cu$

CBI Group: Annie, Anna and Amy

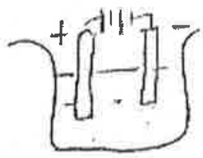
In the pre-test, Annie, Anna and Amy did not answer this question. None of the interviewees in this group knew the correct scientific concept needed to answer the question. In the post-test, Annie, who gave a correct definition of anode in

Question 1b, wrote a partially correct answer to Question 4. She wrote that the cathode in the electrolytic cell is negatively charged, "because it receives ē [electrons] from the battery whereas the cathode in the galvanic cell is producing ē [electrons]". The answer given by Annie that the "cathode in the galvanic cell is producing ē [electrons]" was incorrect because the cathode does not produce electrons in the first place, but rather receives the electrons from the anode.

Annie tried to justify her answer by using the words 'receives electrons' for the electrolytic cell and the words 'producing electrons' for the galvanic cell. However, Annie's explanation revealed her misconceptions evident in her interview responses:

Researcher: **Draw an electrolytic cell of $PbBr_2$ molten.**

Annie: **[Draws an electrolytic cell].**



Researcher: **Which is the negative terminal and which is the positive terminal?**

Annie: **Cathode is the negative and anode is the positive.**

Researcher: **Why is cathode negative?**

Annie: **Because it is connected to the negative terminal of the battery.**

However, further questioning indicated that she probably had memorized her answers.

Researcher: **Why is cathode negative and anode positive?**

Annie: **It is opposite to the galvanic cell.**

Researcher: **What about the galvanic cell?**

Annie: **Anode is negative, cathode is positive.**

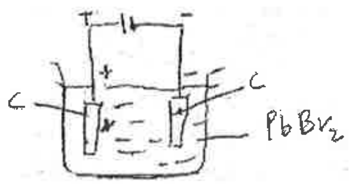
The responses revealed that Annie demonstrated only surface understanding of processes at the molecular level. Although she knew that the cathode in the electrolytic is negatively charged, she had difficulty identifying why the cathode in a galvanic cell is positively charged. Annie tried to provide a plausible explanation in order to reconcile her cognitive conflicts, by saying that the cathode in the electrolytic cell is negative simply because "It is opposite to a galvanic cell."

On the other hand, Amy did not try to answer the question in either the pretest or post-test, whilst Anna failed to not only give the correct answer but also struggled to determine the electrodes for each of the cells. She wrote the statement that "Zn-Cu is positively charged because…" in her post-test answer. The fact is that 'Zn-Cu' has nothing to do with electrical charge. Below are Amy's and Anna's interview excerpts highlighting their understanding of electrode charges in an electrolytic cell and galvanic cell during the interview.

Amy's responses:

Researcher: **Which is the negative terminal and which is the positive terminal?**

Amy: **[Labels electrodes as positive (+) and negative (-)]**



Researcher: **Which is the anode and which is the cathode?**

Amy: **This is the cathode because it is negative [negatively charged]**

Researcher: **Anode?**

Amy: **Anode is the positive electrode.**

Researcher: **Why is anode a positive electrode?**

Amy: **Because it is connected to the battery.**

Researcher: **Can you explain?**

Amy: **Because the battery has the positive sign and negative sign...**

Researcher: **Why is the negative terminal the cathode electrode?**

Amy: **Because I remembered that cathode is negative and anode is positive.**

Researcher: **Which electrode is anode or cathode [for a galvanic cell]?**

Amy: **Copper is anode.**

Researcher: **Why?**

Amy: **Anode...is positive electrode.**

Amy knew that the cathode in an electrolytic cell is negatively charged and the anode is positively charged. However, she had difficulty identifying why the cathode is negatively charged and why the anode is positively charged. Amy seemed to use her rote-memorization by saying "Because I remembered that cathode is negative and anode is positive..." statement. She also failed to determine which electrodes in a galvanic cell are the cathode and the anode.

Anna's responses

Researcher: **Why is the cathode [in the electrolytic cell] a negative terminal?**

Anna: **Because it has a lot of electrons.**

Researcher: **How do you know that?**

Anna: **Electrons have negative charge.**

Researcher: **What about the galvanic cell?**

Anna: **I think it should be reversed [compared to electrolytic cell].**

Anna shared almost the same view as Annie and Amy. However, she knew that the cathode in the electrolytic cell was negatively charged because "it has a lot of electrons." Further questioning indicated that she encountered some difficulties trying to describe the electrical charges of electrodes in a galvanic cell by saying "I think it should be reversed."

The above findings revealed that interviewees in the CBI group demonstrated little understanding of what occurs at the molecular levels in an electrolytic and a galvanic cell as well as having difficulty identifying which electrodes were negatively or positively charged. During the interviews, the interviewees showed uncertainty about the chemical processes that occurred at the electrode anode and cathode, therefore showing uncertainty about the assignment of electrodes as positive or negative terminals, especially for the galvanic cell.

CAnI Group: Sarah, Sally and Sofia

In the pre-test, Sarah and Sofia had tried to answer Question 4. Sarah wrote that "molten KCl is negatively charged because it gains electrons from the anode" which is incorrect and meaningless because molten KCl is not a cathode. Meanwhile, Sofia wrote that the cathode in molten KCl cell is negatively charged because "K [sodium] is on the top of the Chemical Reaction Series [the Electrochemical Series].... Zn-Cu below the Chemical Reaction Series." Again, Sofia referred to molten sodium and Zn-Cu, both as electrodes, which was irrelevant to the question.

However, in the post-test Sarah and Sally provided correct answers whilst Sofia was partially correct. Sarah wrote that the cathode in the electrolysis cell (molten $PbBr_2$) is negatively charged because "it contains an excess of electrons…[from the battery]" whilst the cathode in the galvanic cell is positively charged because "it gives ē [electrons]". Sally gave the answer that the cathode in the electrolysis cell of molten $PbBr_2$ is negatively charged because "it accepts / gains electrons from the battery" whilst the cathode in the galvanic cell is positively charged because "it releases electrons". Meanwhile, Sofia explained that the cathode in the electrolytic cell is negatively charged because the "cathode is connected to the negative part [of the battery]."

Sarah, Sally and Sofia seemed to have some understanding of the reason why the cathode in electrolytic cell is negatively charged, but is positively charged in the galvanic cell. It may be concluded that students interviewed from the CAnI group experienced strong conceptual change because their existing knowledge was restructured to accommodate newly related knowledge.

In summary, after attending electrochemistry instruction, interviewees in the CBI group failed to give completely satisfactory answers. Although both groups can be considered as having experienced some conceptual change, the overall analysis illustrates better understanding amongst interviewees in the CAnI group compared to those in the CBI group. Perhaps, the most interesting finding was that interviewees in the CBI group memorized the signs of electrodes based on the cathode electrode of electrolytic cell as a point of reference as depicted in Figure 23.

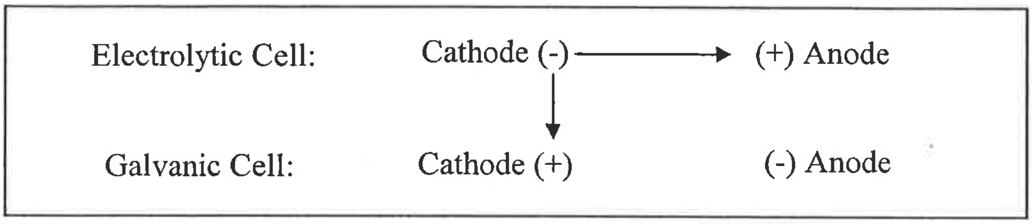


Figure 23. The CBI group memorized the signs of electrodes.

The CBI group's limited conceptual change may well be a consequence of the rote-memorization and over-simplification of information as commonly practiced in conventional chemistry instruction. In fact, memorizing or remembering scientific information is not necessarily accompanied by deep understanding of the concepts. This finding suggests that CAnI can become a starting point of a new instructional innovation based on constructivist learning theory. Realizing that chemistry teachers in Malaysia are "stuck" within the implementation of direct transmission approach (focus on student acquisition of information) and instructional methods that are constructivist and IT rich (focus more on deep understanding and inquiry processes) as stressed and encouraged by the MOE, this finding suggests that CAnI can become a starting point of a new instructional innovation based on constructivist learning theory. This finding also suggests the benefit of CAnI in encouraging students' participation in active and extended inquiry science instruction.

Section A - Question 5

In a galvanic cell, is the more active (reactive) metal more likely to be the anode or the cathode? Briefly explain your opinion.

Question 5 examines the indirect relationship between an active metal and the electrode preference. The question aims to achieve objective k in the lesson plan Unit 1 and objective d in lesson plan Unit 3 (refer to Appendix A). This question was constructed to test the ability of interviewees to analyze the concept that active metals have a greater tendency to release or donate electrons (oxidation process) than less active metals, as arranged in the Electrochemical Series. Active metals are therefore more likely to be the anode than the cathode. The possible sequence of the conceptual sets for this question is:

Easy to release electrons ⟷ Oxidation (reducing agent) ⟷ Anode

Easy to gain electrons ⟷ Reduction (oxidizing agent) ⟷ Cathode

CBI Group: Annie, Anna and Amy

There was no response at all from Annie, Anna and Amy for this question in the pre-test. Annie, Anna and Amy probably did not know how to relate the reactivity of metals with the electrode preference. Surprisingly, all of them gave correct answers in the post-test. They described the phenomenon as follow:

Annie wrote: ...the anode because they are <u>giving out electrons.</u>
Anna wrote: ...the anode because anode is the stronger <u>reducing agent.</u>
Amy wrote: ...the anode because anode is <u>reducing agent.</u>

Annie, Anna and Amy all identified the anode but based on different features. Annie associated the anode with "giving out electrons", whilst Anna and Amy associated the anode with "reducing agent." No one related an active metal (as opposed to less reactive metals) with the preference to lose electrons or preference to undergo the oxidation process, as the basis of their explanation.

This finding suggested that the concepts underlying the question were intelligible or made sense to the interviewees in the CBI group. It is evident that the interviewees in the CBI group experienced conceptual change.

CAnI Group: Sarah, Sally and Sofia

In the pre-test, Sally and Sofia gave completely wrong and irrelevant explanations even though they tried to answer Question 5. For example, Sally gave the answer as 'the anode because it can attract atoms that have negative charge.' This demonstrated her unconnected and irrelevant existing ideas. However, in the post-test, all of them gave the correct answer. In the post-test, Sarah, Sally and Sofia described the phenomenon as follows:

Sarah wrote:	**"The anode, it is because the more reactive metal are more preferable to release electrons to perform oxidation."**
Sally wrote:	**"The anode because active metal will donate the electron."**
Sofia wrote:	**"The anode because it is the place where the oxidation happen...anode must be the stronger reducing agent."**

Sarah identified the anode based on the logical possible idea that active metals prefer to release electrons and undergo the process of oxidation. Sally gave a straightforward answer that the anode donates electrons. Sofia chose to explain that active metals are strong reducing agents and undergo oxidation. This finding suggested that the concepts underlying the question were intelligible and plausible to the interviewees in the CAnI group. Sarah's, Sally's and Sofia's responses show evidence of a better conceptual change to the extent that their explanations were more correct and explicitly described compared to the CBI group.

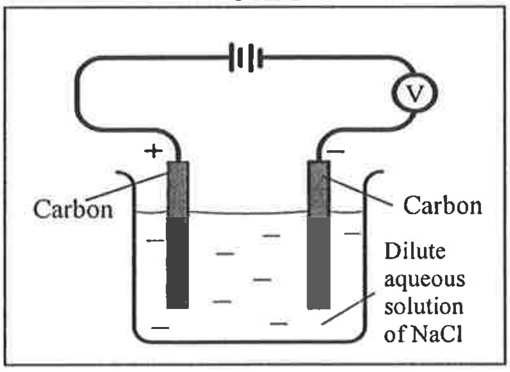
In summary, the fact that both groups gave correct answers in the post-test for this question about the reactivity of metals and electrode preference indicated that all interviewees experienced conceptual change. However, the findings revealed that interviewees in the CBI group demonstrated only partial understanding of the concept that active metals have a greater tendency to release or donate electrons (oxidation process) than less active metals. On the other hand, the interviewees in the CAnI group were more likely to give better conceptual explanation, thus indicating stronger conceptual change.

Section B - Question 1

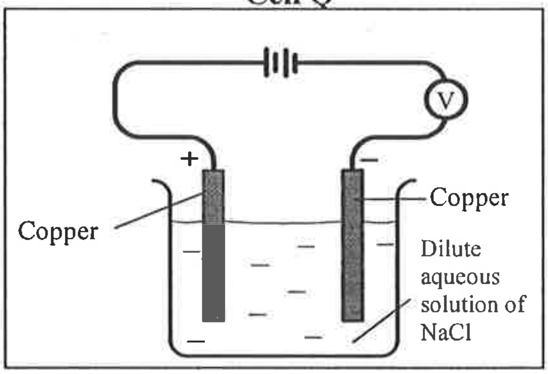
You are given two electrolytic cells, Cell P and Cell Q, as shown below:

a. State (i) the reactions that occur at the anode and the cathode and (ii) the physical observations when electric current passes through each cell.

Cell P



Cell Q



Write your answer by completing the table below.

	Electrode cathode		Electrode anode	
Cell	(i) Equation of the reaction	(ii) Observation	(i) Equation of the reaction	(ii) Observation
P	$2H_2O + 2e \longrightarrow H_2 + 2OH^-$	Bubbles released		
Q				

b. In your opinion, which electrolytic cell is more suitable for electroplating - Cell P or Cell Q? Give your reasons.

Question 1a examines the interviewee's ability to answer a question of how an electrolytic cell works. This question concerns the factors affecting electrolysis of aqueous solution based on the objectives a. to f. in lesson plan Unit 2 (refer to Appendix A). The factors discussed are:

(i) The Electrochemical Series (the preference for oxidation and reduction based on the position of ions in the Electrochemical Series).

(ii) Nature of electrodes (the preference for oxidation at anode to occur at the more reactive metal)

In Question 1a, dilute aqueous solution of NaCl in Cell P (non-reactive carbon electrodes) is compared to a concentrated aqueous solution of NaCl in Cell Q (reactive metal electrodes). For cell P, students should apply the Electrochemical Series in predicting the reactions that occur in the cell. For cell Q, students should apply the nature of electrodes. The answers for Cell P are shown below:

	Cathode		Anode	
Cell	(i) Equation of the reaction	(ii) Observation	(i) Equation of the reaction	(ii) Observation
P	$2H_2O + 2e \longrightarrow H_2 + 2OH^-$	Bubbles released	$2H_2O \longrightarrow O_2 + 4H^+ + 4e$	Bubbles released

The possible sequence of concepts for ion selection at the cathode is:

Reduction ⟷ Gain electrons ⟷ Species for half-reaction (Na^+ or H_2O)

Based on the Electrochemical Series, H_2O is expected to be reduced in preference to Na^+:

$$2H_2O + 2e \longrightarrow H_2 + 2OH^-$$

The possible sequence of concepts for ion selection at the anode:

Oxidation ⟷ Lost electrons ⟷ Species for half-reaction (Cl^- or H_2O)

Based on the Electrochemical Series, H_2O is expected to be oxidized in preference to Cl^- :

$$2H_2O \longrightarrow O_2 + 4H^+ + 4e$$

The answer of Cell Q is shown below:

	Cathode		Anode	
Cell	(i) Equation of the reaction	(ii) Observation	(i) Equation of the reaction	(ii) Observation
Q	$Cu^{2+} + 2e \longrightarrow Cu$	Solid metal deposited	$Cu \longrightarrow Cu^{2+} + 2e$	Anode dissolved / reduced in mass

The possible sequence of concepts for ion selection at the anode for Cell Q is:

Oxidation ⟷ Lost electrons ⟷ Species for half-reaction (Cl^-, H_2O or Cu)

The most reactive metal undergoes oxidation at the anode. Therefore, Cu is expected to be oxidized to form Cu^{2+} in preference to Cl^- and H_2O.

$$Cu \longrightarrow Cu^{2+} + 2e$$

The possible sequence of concepts for ion selection at the cathode:

Reduction ⟷ Gain electrons ⟷ Species for half-reaction (H_2O or Cu^{2+})

Based on the Electrochemical Series, Cu^{2+} is expected to be reduced in preference to Cl^- and H_2O to form Cu and consequently plate the cathode:

$$Cu^{2+} + 2e \longrightarrow Cu$$

For Question 1b, the answer is cell Q. The anode produces positive copper ions, and then accepts electrons from the cathode to convert copper ions into atoms. These copper atoms are then deposited as copper metal on the cathode completing the electroplate process.

CBI Group: Annie, Anna and Amy

Pretest – Question 1a

In the pre-test, Annie, Anna and Amy did not write any equation in response to this question. This revealed that they did not understand the abstract and complex processes of electrolysis and electroplating.

Post-test – Question 1a

For cell P, Annie wrote Cl^{2+} as the outcome of the reaction that occurred at the anode. Anna, on the other hand, claimed sodium (Na) underwent oxidation at the cathode which was wrong whilst Amy, did not answer the question. It was interesting to note that Annie was confused whether the formula for the chloride ion is Cl^{2+} or Cl^-. Her responses to probing questions:

Researcher: Why did you write Cl^{2+} is attracted to the positive electrode?
Annie: Sorry...chlorine is negative.
Researcher: Rewrite the equation.
Annie: [Writes the equation]

$$Cl^- + 2e \longrightarrow Cl_2$$

Annie failed to determine the electrical charge of chloride ion, which is a basic requirement in writing chemical equations. She also failed to balance a simple equation.

Anna, on the other hand, was completely unaware that the sodium atom (Na) never exists in an aqueous solution because it reacts immediately with water. When asked to elaborate, she replied:

Researcher: **List down all the ions attracted to the cathode in Cell Q.**
Anna: **Na^+.**
Researcher: **Can you predict the reaction?**
Anna: **$Na \longrightarrow Na^+ + e$**
Because Na produced Na^+

The responses revealed that she did not realize water (H_2O) does react during the electrolysis of aqueous solutions. The reaction of sodium to form sodium ion seemed intelligible to Anna but completely incorrect because sodium atoms if present, react vigorously with water.

For Cell Q, Annie gave correct answers to both the observation and equation that occurred at the cathode. She chose Cu^{2+} to undergo oxidation followed by the observation that "the electrode volume [mass] decreased". When asked how she knew copper (Cu) underwent reduction at the electrode cathode for Cell Q, she replied:

Researcher: **How do you know that copper ions receive electrons at the electrode anode?**
Annie: **Because the cathode and Cu^{2+} both are positively charged.**

Annie's choice of Cu^{2+} instead of Cl^- and H_2O as the substance that goes through reduction was because she simply thought that positively charged ion such as Cu^{2+} attracts electron. Even though the answer was correct, she should be able to refer to the Electrochemical Series, and show that Cu^{2+} would be reduced to form Cu in preference to Cl^- and H_2O.

Anna, on the other hand, provided the correct equation only for the anode reaction whilst Amy gave all correct answers to this question. This shows that only Amy was found to possess a deep understanding of the electrolysis of the concentrated aqueous of sodium chloride (cell Q).

<u>Pretest and Post-test – Question 1b</u>

In the pre-test, Annie, Anna and Amy did not write any answer to predict which electrolytic cell was more suitable for electroplating. In the post-test Annie, Anna and Amy gave their answers as follows:

Annie: <u>Cell Q</u> because the solution is more <u>concentrated.</u>

Anna: <u>Cell P</u> because in cell P is <u>dilute aqueous</u> compared to cell Q.

Amy: <u>Cell Q</u> because the electrode copper is more <u>reactive</u> than carbon.

The answer given by Anna was wrong because Cell P used inert electrodes, therefore was not suitable for electroplating. Annie's and Anna's answers were equally incorrect as they gave wrong attributes and incompatibility between the cell chosen and the reason given as explanation to the phenomena. The answers given by Annie and Anna reflected that they lacked deep understanding of factors affecting electrolysis of aqueous solution. Only Amy gave the correct answer. She gave a simple explanation when asked about her answer:

Researcher: **Why did you choose Cell Q for electroplating?**
Amy: **Because it is suitable for electroplating...**
Researcher: **Could you explain?**
Amy: **For electroplating, it must have precipitation.**

Annie's responses during interview:

Researcher: Why did you choose Cell Q for electroplating?
Annie: **I just wrote the answer.**

Anna's responses:

Researcher: Why did you choose Cell Q for electroplating?
Anna: **Just guessing.**

In summary, based on the interviewees' written answers in the post-test and interview transcripts, Annie and Anna failed to understand even the basic yet important concepts such as balancing simple equations, and determining the species to be considered for oxidation or reduction. The above responses evidently show that both of them blindly guessed the answers. The answer given by Amy showed that she associated electroplating with 'precipitation', perhaps influenced by her previous knowledge that electroplating involved what she mentioned as 'precipitation' rather than the correct technical term such as 'deposited on the cathode.' Overall, Annie and Anna in the CBI group were unable to identify the required concepts, possibly indicating that learning did not take place despite formal instruction. If such is the case, then these students cannot be considered as having experienced strong conceptual change.

CAnI Group: Sarah, Sally and Sofia

Question 1a

In the pre-test, Sally and Sofia did not answer the question for Cell P. For Cell Q, Sarah, Sally and Sofia all gave wrong and irrelevant answers. In the pre-test, Sarah predicted the following equations at the anode of cell P:

Sarah's equation: $Na \longrightarrow Na^{+} + e$

Sarah's responses when asked to describe her equation:

Researcher: Why did you choose Na involved at the anode in cell P ?
Sarah: Na is reactive, easy to react.
Researcher: Where does Na come from?
Sarah: From the solution...I guess.

From the above responses, Sarah tried to justify her answer based on her existing ideas that sodium is a reactive metal. The fact that sodium reacts vigorously with water cannot be applied here because sodium metal does not exist in the aqueous solution.

In the post-test, Sarah gave correct answers to both Cell P and Cell Q. Sally gave correct answers to both cells except the equation for Cell P. Meanwhile, Sofia gave correct answers only for Cell P. The results show positive implication of electrochemistry instructions on the interviewees' initial conception change. The answers given by the interviewees are as follows:

Sarah's equation: $2H_2O \longrightarrow O_2 + 4H^{+} + 4e$
Sofia's equation $2H_2O \longrightarrow O_2 + 4H^{+} + 4e$
Sally's equation: $2Cl^{-} + 2e \longrightarrow Cl_2$

Sarah and Sofia correctly chose water (H_2O) as the substance that undergoes the oxidation reaction for Cell P. The concepts seems intelligible to Sarah and Sofia, but not to Sally. When asked probing questions to Sally, she declined to answer:

Researcher: Can negative chloride receive electron?
Sally: I'm not good at [chemical] equations.

Here are Sofia's responses when asked to describe her equation for Cell P to probe her understanding. Sofia's responses:

Researcher: Why do you think water will react at the cathode of cell P?
Sofia: Because it prefers to gain electrons compared to Na^+
Researcher: How do you know?
Sofia: Here, from the Electrochemical Series.

Question 1b

In the pre-test, Sarah, Sally and Sofia did not even try to answer the question. In the post-test Sarah, Sally and Sofia gave their answers as follows:

Sarah: Cell Q...copper is able to go through redox...the copper that gain electrons can be plated...
Sally: Cell Q because Cu is more reactive than C [in Cell P].
Sofia: Cell Q because the copper [anode] can be oxidized to Cu^{2+} and the ē received at the cathode for reduction...

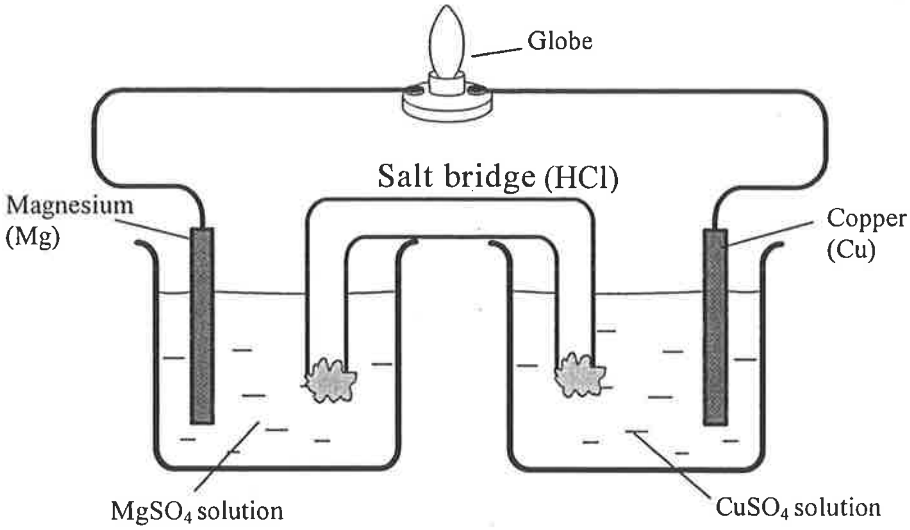
In Cell Q, copper dissolves from the anode to form positive metallic ions, Cu^{2+}. At the cathode, Cu^{2+} is reduced and forms a copper plate. Even though the answers given by Sarah, Sally and Sofia did not directly follow this sequence of ideas, they were able to use the words 'redox', 'oxidize' and 'reactive', reflecting that they had acquired some ideas about electroplating process. It can be argued that strong conceptual change had taken place as Sarah, Sally and Sofia correctly described why they chose Cell Q instead of Cell P as suitable for electroplating.

In summary, it is obvious that the question regarding the whole process of electrolytic cells (Cell P and Cell Q) was complex and abstract, requiring dynamic understanding of the whole process. Nearly all interviewees from both groups possessed inadequate existing knowledge to answer the questions in the pre-test, even though the topic had already been taught in form IV, the fourth year of secondary school.

It can be seen that interviewees who were exposed to CAnI were generally better in terms of conceptual change when compared with interviewees who were exposed to CBI. In the post-test, the answers given by the interviewees in the CAnI group improved drastically and tended to follow a logical sequence. The answers given by the interviewees in the CAnI group showed better understanding of electrolytic and galvanic cells.

Section B - Question 2

A simple galvanic cell can be built as shown below. Both magnesium (Mg) and copper (Cu) electrodes are connected to the terminals of a low power light globe.



a. Explain what happens at the Mg electrode and Cu electrode when the cell is completed. Write the half-cell equation of the reactions at both electrodes.

b. Prepare the same galvanic cell by replacing the HCl salt bridge with an 'alcohol salt bridge'. Predict what will happen to the lighting of the low power light globe as compared the one that used the HCl salt bridge. Give your reasons. (Students were told that an 'alcohol salt bridge' is prepared by filling a U tube with alcohol, replacing hydrochloride acid solution.)

Questions 2a and 2b consist of at least three processes involved in a galvanic cell that occur simultaneously at the microscopic level – reduction at the electrode cathode, oxidation at the electrode anode and, electron flow through the external circuit. For Question 2a, since the magnesium electrode is more easily oxidized than copper, electrons are lost by magnesium and transferred through the external wire. Thus, the magnesium is dissolved as Mg^{2+}. Simultaneously, the copper ions (Cu^{2+}) from the $CuSO_4$ solution are being reduced to form copper atoms and deposited on the copper electrode, thus causes the flow of anions (Cl^-) from the salt bridge into the $MgSO_4$ solution to balance the excess of Mg^{2+} and the flow of anions (H^+) into the $CuSO_4$ solution to balance the excess of SO_4^{2-}.

The possible sequence of concepts for oxidation is as follows:

Oxidation $\longleftrightarrow$ Release electron $\longleftrightarrow$ Species to be oxidized (Mg or Cu)

Based on the Electrochemical Series, Mg is expected to be oxidized to form Mg^{2+} in preference to Cu. The equation for oxidation is as follows:

$$Mg \longrightarrow Mg^{2+} + 2e$$

The possible sequence of concepts for reduction is as follows:

Reduction $\longleftrightarrow$ Gain electron $\longleftrightarrow$ Species to be reduced (Cu^{2+} or H_2O)

Based on the Electrochemical Series, Cu^{2+} is expected to reduce to form Cu in preference to water.. The equation is as follows:

$$Cu^{2+} + 2e \longrightarrow Cu$$

For Question 2b, the globe does not light up because the alcohol does not provide ions to balance the electrical neutrality. As reported by Ozkaya, Uce and Sanin (2004), if a salt bridge is replaced by substances other than an electrolyte (for example a metal), the current reading is very low and could be ignored. For this question, oxidation of magnesium (Mg) produces additional magnesium ions (Mg^{2+}), whilst the copper ion (Cu^{2+}) solution becomes less concentrated as Cu^{2+} is reduced to copper atom (Cu). Oxidaton and reduction cannot continue unless there is a way to remove the charge imbalance that builds in both the cathode and anode compartment. Replacing the HCl solution in the salt bridge with alcohol does not satisfy this requirement. Alcohol does not provide ions to migrate between the anode and cathode compartments, thus diminishing the flow of electricity as the charge imbalance cannot be rectified.

CBI Group - Annie, Anna and Amy

Question 2a:

In the pre-test, Annie, Anna and Amy did not write any half-cell equations. It appears they had no idea how the cell worked. In the post-test, Anna and Amy gave the correct redox reactions. Annie, on the other hand, gave erroneous reactions. The following are the answers given by Annie, Anna and Amy in the post-test:

Annie's answers:

$$\mathbf{Cu \longrightarrow Cu^{2+} + 2e}$$
$$\mathbf{Mg^{2+} + 2e \longrightarrow Mg}$$

Anna's answer:

$$\mathbf{Cu^{2+} + 2e \longrightarrow Cu}$$
$$\mathbf{Mg \longrightarrow Mg^{2+} + 2e}$$

Amy's answers:

$$\mathbf{Cu^{2+} + 2e \longrightarrow Cu}$$
$$\mathbf{Mg \longrightarrow Mg^{2+} + 2e}$$

The answers above revealed that Annie might not be aware that magnesium (Mg) is more reactive and releases electrons more easily than copper (Cu). When asked why she chose the copper atom and not the copper ion she replied:

Researcher: What made you choose copper releases electrons?

Annie: I'm not really sure...just guessing.

Anna's responses:

Researcher: **Why did you choose Cu^{2+} ?**

Anna: **Because copper receives electrons.**

Researcher: **Where does the Cu^{2+} come from?**

Anna: **From the copper electrode.**

Amy's responses:

Researcher: **Why did you choose that Cu^{2+} is reduced and Mg is oxidized?**

Amy: **Mg is above copper in the electrochemical series...Mg is more electropositive and easier to oxidized.**

Anna failed to realize that magnesium electrode is easier to donate electrons than copper. She blindly guessed that copper electrode was oxidized.

Question 2 b:

For Question 2b, Annie, Anna and Amy did not respond to the pre-test question at all. In the post-test, all of them gave correct predictions to the lighting of the low power light globe. However, each one gave a different reason as follows:

Annie: there is no electrons movement.

Anna: because alcohol is the weak acid compare to HCl.

Amy: alcohol is covalent molecule, so it has no free moving electrons.

As the globe needs electrical current in order to light up, Annie and Amy associated the electrical current with moving electrons in their answers. Annie gave the following responses:

Researcher: **You answer is "there is no electron movement so, globe will not light up", why?**

Annie: **No electron movement in the salt bridge.**

Researcher:	**What do you mean that 'electrons in the circuit or in the salt bridge?'**
Annie:	**I'm not sure.**

Anna then described her opinion:

Researcher:	**What do you think will happen if alcohol is used instead of HCl aqueous solution?**
Anna:	**The light bulb will <u>not light</u> as brightly.**
Researcher:	**Why is this so?**
Anna:	**A<u>lcohol is weak acid.</u>**
Researcher:	**How do you know that alcohol is a weak acid?**
Anna:	**HCl is a strong acid, so alcohol is a weak acid.**

In another interview, Amy expressed her opinion:

Researcher:	**What do you think will happen if alcohol is used instead of HCl aqueous solution?**
Amy:	**The globe will <u>not light up.</u>**
Researcher:	**Why?**
Amy:	**Because <u>alcohol is a covalent</u> molecule.**

From the above responses, Annie assumed that the electrons move through the salt bridge instead of the wire or external circuit. She thought that the salt bridge conducts electrons, instead of ions to complete the circuit. Even though Annie had the idea of "moving electrons", she failed to explain how these electrons maintain electrical neutrality in galvanic cells. Meanwhile, Anna mentioned that alcohol is a weak acid. She might think that alcohol is a 'weak acid' since it replaced the HCl aqueous solution (strong acid). Amy, on the other hand, mentioned that there were 'no free moving ions' because alcohol is a 'covalent molecule'.

Annie's misconception is consistent with one of the documented misconceptions regarding the galvanic cell that 'electrons can flow through aqueous solution without assistance from the ions'. The idea is that in galvanic cells, electrons enter the electrolyte through the salt bridge. This misconception is commonly found in previous studies (see Garnett & Treagust, 1992; Huddle & Margaret, 2000; Ozkaya, 2002; Sanger & Greenbowe, 1997b). Meanwhile, Anna gave irrelevant reasons to what caused the failure of the globe to light. Amy, on the other hand, only mentioned that alcohol is a covalent molecule. She should explain that alcohol does not permit the exchange of ions because it consists of covalent molecules.

CAnI Group -Sarah, Sally and Sofia

Question 2a:

In the pre-test, Sally and Sofia did not write any half-cell equations. Only Sarah gave correct half-cell equations but failed to give any explanation. In the post-test, all of them wrote down the correct equation:

Sarah's, Sally's and Sofia's answers:

$$\mathbf{Cu^{2+} + 2e \longrightarrow Cu}$$
$$\mathbf{Mg \longrightarrow Mg^{2+} + 2e}$$

Further questions were then asked to probe their understanding. Here are the responses by the interviewees.

Sarah's responses:

Researcher: **What happen to the magnesium electrode?**

Sarah: **It releases ions.**

Researcher: **Why did you choose magnesium (to release ions) instead of copper?**

Sarah: **Because magnesium is more reactive than copper.**

Sally's responses:

Researcher: **Why did you choose Mg undergo oxidation?**

Sally: **Based on the position of Mg [located above copper] in the Electrochemical Series.**

Sofia's responses:

Researcher: **Why did you choose magnesium undergo oxidation?**

Sofia: **Because it is located above the series of electrochemistry.**

All of the interviewees chose the magnesium electrode to undergo oxidization as it is located above copper (Cu) in the Electrochemistry Series.

Question 2b:

For Question 2b, Sarah, Sally and Sofia left the pre-test question unanswered. In the post-test, none of them gave the correct answers since they predicted that the globe will light up based on the following reasons:

Sarah: when alcohol is used, there will be <u>a lot of ions.</u>
Sally: alcohol is suitable substance to produce <u>more ions.</u>
Sofia: more [alcohol] molecules are in <u>ions.</u>

Interestingly, although Sarah, Sally and Sofia gave erroneous explanations, all of them associated the existence of an electrical current that lights up the globe with the presence of ions in the salt bridge. The following excepts further emphasize this understanding:

Sarah's responses:

Researcher:	**What do you think will happen if alcohol is used as a salt bridge?**
Sarah:	**The light bulb will <u>light brighter.</u>**
Researcher:	**Why?**
Sarah:	**Maybe...because alcohol release <u>more ions.</u>**

Sally's responses:

Researcher:	**Why did you think that the bulb light up?**
Sally:	**Alcohol releases more ions.**
Researcher:	**What did you mean by alcohol has <u>more ions</u>?**
Sally:	**Ions have positive and negative charge...**
Researcher:	**Can you explain?**
Sally:	**That all I know...**

Sofia's responses:

Researcher:	**Why is that the bulb <u>will light up</u> if we use alcohol?**
Sofia:	**Alcohol is covalent molecule that has <u>more ions</u> like CH_3COOH.**
Researcher:	**What is CH_3COOH [ethanoic acid]?**
Sofia:	**It is methanol.**

From the responses given above, Sarah, Sally and Sofia assumed that the existence of more ions in the salt bridge lights up the globe. All of them tended to associate the purpose of the salt bridge with the existence of ions, and hence complete the electrical circuit. Alcohol does not produce ions since alcohol is a covalent molecule. This shows that the interviewees understand the function of the salt bridge but incorrectly believe that alcohol provides ions.

In summary, the analysis shows that almost all subjects in both groups (except one in the CBI group) correctly answered the question regarding the half-cell reactions at the magnesium (Mg) and copper (Cu) electrodes in the galvanic cell. All interviewees in the CBI group correctly predicted that the globe would not light. Although the prediction was correct, the reasons given do not fit with the function of the salt bridge. They believed that a salt bridge provides a pathway for the flow of electrons. The salt bridge provides ions (not electrons) to migrate between the anode and cathode compartments. All interviewees in the CAnI group incorrectly predicted that the globe would light, but they did realize that the salt bridge needed to produce ions for the globe to light. Their mistake was in believing alcohol could release such ions.

The answers given by the subjects in the CAnI group were closer to the function of the salt bridge whilst the answers given by the interviewees in the CBI group stated the correct prediction, but provided the wrong explanation for the phenomenon. It is suggested that the interviewees in the CAnI group had grasped the main idea that ions transferred the electrical charge through the salt bridge but erroneously believed that alcohol could produce ions in significant concentrations. The interviewees in the CBI group did not express a clear concept of a salt bridge's function, suggesting only surface learning had taken place. If such is the case, the interviewees in the CAnI group can be considered as having experienced stronger conceptual change compared to the interviewees in the CBI group. This is an example that shows how qualitative analysis can be a tool to gain more in-depth information that may be difficult to convey quantitatively (Hoepfl, 1997). For Jayaratne (1993, p. 117). "qualitative data can support and explicate the meaning of quantitative research." Qualitative analysis through unstructured interviews used in this study allows a clear picture of the subject's level of understanding of the concepts being discussed.

Interviewee's drawing of electrochemistry cells

Interviewees were asked to draw simple electrolytic and galvanic cells. The purpose of this exercise was to uncover the understanding of how they approached to determination of the anode and cathode electrodes for each cell.

CBI Group -Annie, Anna and Amy

Figures 24 to Figure 29 below are the sketches by Annie, Anna and Amy which represented their models of the electrolytic and galvanic cells:

Annie's drawing:

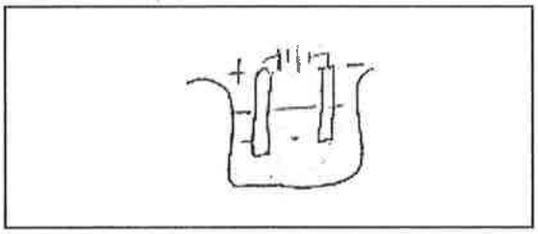


Figure 24. Annie's drawing represented her model of electrolytic cell.

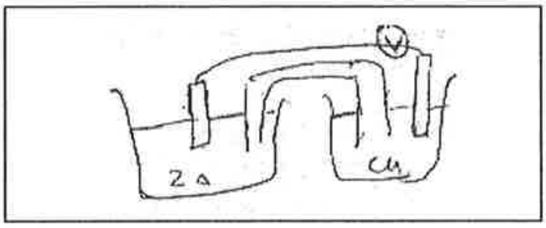


Figure 25. Annie's drawing represented her model of galvanic cell.

Anna's drawing:

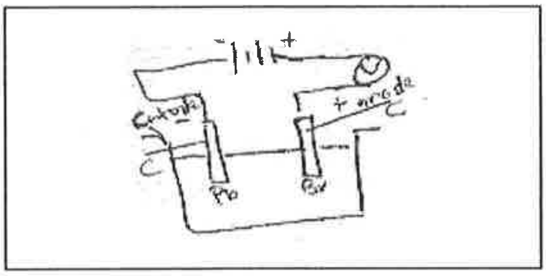


Figure 26. Anna's drawing represented her model of electrolytic cel*l*.

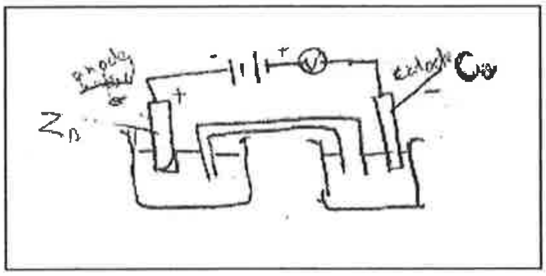


Figure 27. Anna's drawing represented her model galvanic cell.

Amy's drawing:

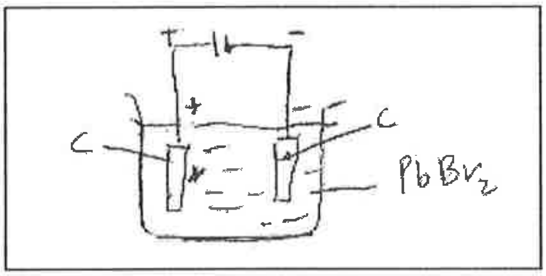


Figure 28. Amy's drawing represented her model of electrolytic cell.

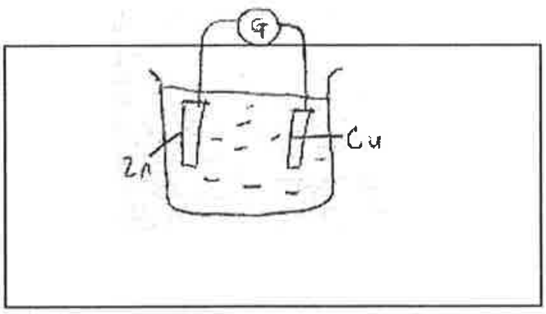


Figure 29. Amy's drawing represented her model of galvanic cell.

Figures 24, 26 and 28 are Annie's, Anna's and Amy's drawings of electrolytic cells, which were very similar to each other's. When asked further probing questions, they exhibited different ideas in their determining of the negative terminal.

Annie's responses:

Researcher: **Which is the negative terminal and which is the positive terminal [for electrolytic cell]?**

Annie: **Cathode is the negative terminal and anode is the positive terminal.**

Researcher: **Why is the cathode a negative electrode?**

Annie: **Because it connects to the negative terminal of the battery.**

Anna's responses:

Researcher: Why is cathode a negative terminal?

Anna: **Because it has a lot of electrons.**

Researcher: How do you know?

Anna: **Electrons have negative charge.**

Amy's responses:

Research: **Which is the anode and which is the cathode?**

Amy: **This is cathode because it is negative.**

Research: **Can you explain?**

Amy: **Because the battery has the positive and negative signs...**

All the subjects correctly sketched a simple electrolytic cell. The responses above clearly showed that they associated the negative terminal of the cell or the cathode with the negative terminal of the battery. Although they correctly identified the cathode, none of the interviewees was able to explain that the cathode has gained electrons from the battery. The findings showed that they held only partial understanding by saying that "the battery has the negative signs" or "it connects to the negative terminal of the battery" which was probably derived from direct observation of the illustrations in the textbook or those given during the formal instruction.

Figures 25, 27 and 29 are Annie's, Anna's and Amy's drawing of galvanic cells. Only Annie sketched the correct diagram of the galvanic cell. Anna's sketch indicated that she was not aware that the reactions in the galvanic cell occur spontaneously to produce electricity; therefore the use of batteries is not necessary. The worst sketch came from Amy. She ignored the salt bridge as one of the important and essential parts of a galvanic cell. When asked why she thought that her sketch represents a galvanic cell, Amy mistakenly believed 'because it has a Galvanometer…galvanic cell doesn't need batteries…it needs Galvanometer…' Even though Amy incorrectly sketched the galvanic cell, she was able to give the correct answer to the question regarding the galvanic cell in the post-test.

Their responses to the question about how they knew which electrode is the anode and which is the cathode for the galvanic cell are given below:

Annie's responses:

Researcher: **Which electrode is anode and which is cathode for galvanic cell?**

Annie: **I'm not sure, I'm confused** [in the post-test she wrote a wrong reaction for the Mg-Cu galvanic cell and failed to explain why the cathode in Zn-Cu was positively charged].

Anna's responses:

Researcher: **Which is anode and which is cathode?**

Anna: **I think zinc undergoes oxidation…anode, so Cu is cathode** [in the post-test she wrote a correct redox reaction for the Mg-Cu galvanic cell but failed to explain why the cathode in Zn-Cu is positively charged].

Amy's responses:

Researcher: **Which electrode is anode and which is cathode?**

Amy: **Copper is anode.**

Researcher: **Why?**

Amy: **Anode…a positive electrode** [in the post-test she wrote a correct redox reaction for the Mg-Cu galvanic cell but failed to explain why the cathode in Zn-Cu is positively charged]

In response to the questions above, none of the interviewees was able to explain that the cathode in the galvanic cell is positively charged because it releases electrons and the anode is negatively charged because it has a deficiency of electrons. The responses above revealed that the interviewees in the CBI group possessed partial understanding of the assignment of electrodes as positive (+) or negative (-) in a galvanic cell.

When asked about the function of a salt bridge, each subject gave different opinions.

Annie's responses:

Researcher: **Why do you need a salt bridge?**

Annie: **To complete the circuit…**

Researcher: **Could you describe further?**

Annie: **To connect the solutions.**

Researcher:	**What do you think will happen if there is no salt bridge?**
Annie:	**Electrons cannot be transferred.**

Anna's responses:

Researcher:	**What is the purpose of the salt bridge?**
Anna:	**To complete the cell.**
Researcher:	**How is it so?**
Anna:	**It allows electrons to flow.**

Amy's responses:

Researcher:	**What is the function of the salt bridge?**
Amy:	**To complete the circuit.**
Researcher:	**How does it complete the circuit?**
Amy:	**It has free ions…so it completes the circuit.**
Researcher:	**How do the free ions complete the circuit?**
Amy:	**Huh…[silent]**

Annie correctly sketched a galvanic cell but did not know how to identify the cathode. She also failed to answer the question regarding the galvanic cell in the pre-test and post-test. However, Anna gave the correct answer by specifying that it was zinc that underwent oxidation. It can be assumed that Anna knew zinc is more reactive than copper. Meanwhile, Amy gave an incorrect answer because she wrongly chose copper as the anode, even though she gave the correct answer in the post-test regarding the galvanic cell.

Both Annie and Anna referred to the function of the salt bridge as completing 'something'. Annie said that the salt bridge was used to complete the circuit while Anna said it was used to complete the cell. Both of them associated a salt bridge with the production of electrons in order to complete the circuit or cell. The word 'complete' could have been a satisfactory answer for the interviewees. Meanwhile, Amy focused more on the galvanometer to justify her galvanic cell. She ignored the essential purpose of a salt bridge in the galvanic cell as long as there are electrons flowing in the cell. These analyses indicated that the interviewees in the CBI group had partial understanding regarding the galvanic cell.

CAnI Group (Sarah, Sally and Sofia)

Figures 30 to 35 below are the sketches of electrolytic and galvanic cells by the subjects in the CAnI group.

Sarah's drawing:

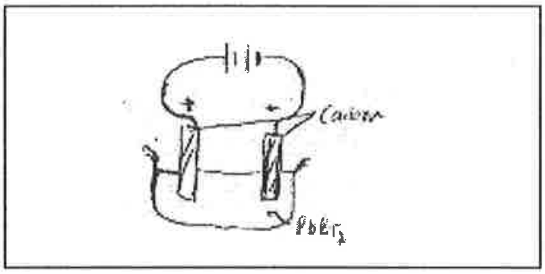


Figure 30. Sarah's drawing represented her model of electrolytic cell.

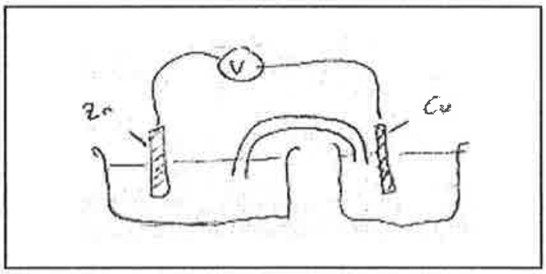


Figure 31. Sarah's drawing represented her model of galvanic cell.

Sally's drawing:

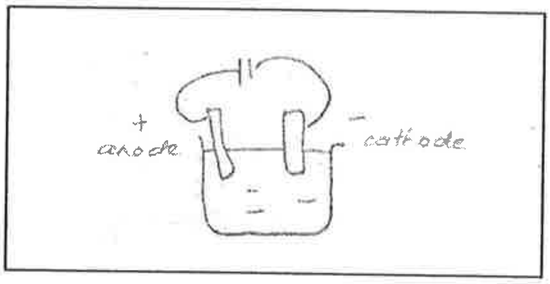


Figure 32. Sally's drawing represented her model of electrolytic cell.

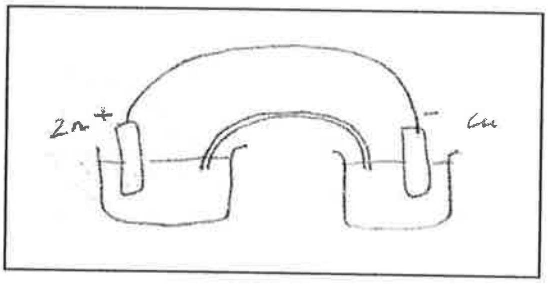


Figure 33. Sally's drawing represented her model galvanic cell.

Sofia's drawing:

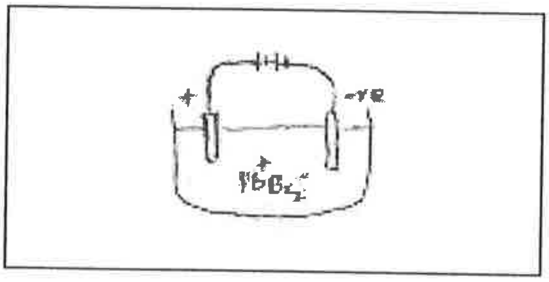


Figure 34. Sofia's drawing represented her model of electrolytic cell.

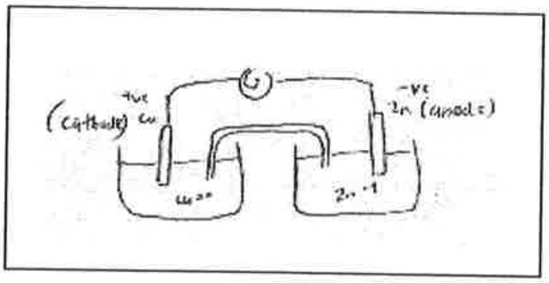


Figure 35. Sofia's drawing represented her model of galvanic cell.

The responses to the question of how the interviewees knew which electrode is positive or negative are stated below:

Sarah's responses:

Researcher: What made you choose the electrode as negative electrode?

Sarah: It is connected to the battery...which flow charges.

Researcher: The battery flow charges?

Sarah: The battery flow the electrons...

Sally's responses:

Researcher: Why is the electrode cathode negatively charged?

Sally: Because it receives electrons from the battery...

Sofia's responses

Researcher: Which is the negative terminal?

Sofia: Here [see Figure 34].

Researcher: Why?

Sofia: Because it is connected to battery's negative terminal.

Interviewees in the CAnI group correctly sketched a simple electrolytic cell. Like the CBI group, they also seemed to associate the negative terminal of the cell with the negative terminal of the battery. However, Sarah and Sally further explained that the negative terminal was caused by the flow of electrons from the battery.

Figures 31, 33 and 35 show the sketches of the Sarah's, Sally's and Sofia's galvanic cell. In answering the question of how they determined the anode and cathode, they made the following responses:

Sarah's responses:

Researcher: **Which is anode?**

Sarah: **Zn…Zn is more reactive.**

Sally's responses:

Researcher: **Why does Zn have positive charge [see Figure 33]?**

Sally: **Electrons were released…**

Sofia's responses:

Researcher: **Which is anode and which is cathode?**

Sofia: **This one and this one [see Figure 35].**

Researcher: **Write down the equation.**

Sofia: **[Write the equation below – Zn releases electrons].**

$$Zn \longrightarrow Zn^{2+} + 2e$$

$$Cu^{2+} + 2e \longrightarrow Cu$$

All interviewees in the CAnI group gave consistent answers. They chose zinc as the electrode anode because according to the Electrochemical Series, zinc tends to lose electrons (more electropositive) compared to copper. The responses were also consistent with their answers in the post-test questions regarding the galvanic cell. When asked about the function of a salt bridge, Sally and Sofia gave almost the same responses. Sarah however gave a different opinion.

Sarah's responses:

Researcher: **What is the purpose of the salt bridge?**

Sarah: **To balance the electrons' charges.**

Researcher: **What is the charge of electrons?**

Sarah: **[Silent]**

Sally's responses:

Interview: What is the function of the salt bridge?

Sally: To complete the circuit....

Interview: How does the salt bridge complete the circuit?

Sally: It has positive and negative ions......to balance the charges.

Sofia's responses:

Interview: What is the purpose of the salt bridge?

Sofia: To complete the circuit.

Interview: Could we replace it with wire?

Sofia: No, because the salt bridge maintains the ions.

In response to the question regarding the purpose of the salt bridge, Sofia, Sally and Sofia said that the ions from the salt bridge were used to 'maintain' or to 'balance' the ions in the cell in order to complete the circuit. However, the statement given by Sarah 'to balance the electrons' charges' rather than how these electrons maintain electrical neutrality, reveals her limited conception.

4.7 Conclusions from the qualitative analyses

The purpose of this qualitative analysis was to explore the students' perception of CAnI and CBI and to compare the effectiveness of both instructional approaches in promoting successful conceptual change on electrochemistry concepts. In general, the analysis of the open-ended questionnaire demonstrated the subjects' positive post-instruction perception towards both CAnI and CBI. However, only a small percentage of students in the CBI group considered overhead transparencies as easy to understand. About half of the students in the CBI group indicated that the use of transparencies made teaching process even faster and unimaginable. For the CAnI group, a relatively high percentage of students considered the use of step-by-step discrete animation an easy presentation to understand and rich images that effectively convey the electrochemistry concepts.

The students in the CBI group stated that the teacher's presentation and the use of simplification of facts were the most helpful aspects of using transparencies to improve heir understanding of electrochemistry concepts. They also stated that the teacher's presentation could be improved through better verbal explanation and through the provision of more illustration. This may be related to the previous responses that claimed the use of transparencies made lessons difficult to understand and hard to imagine. Students in the CAnI group clearly claimed that step-by-step discrete animation was one of the most helpful aspects of the teacher's presentation. Their perceptions clearly supports a belief that better verbal explanations and the provision of more animations, improve the teacher's presentation and aid in a fuller understand of electrochemistry concepts.

Although both groups agreed that explanation from the teacher is crucial to promote better understanding, comparison does favor exposure to animation over the use of static illustrations. The main difference between the two is that the CAnI presentation appears superior at enabling students to visualize abstract and dynamic concepts, thus suggesting that animation incorporated in CAnI can serve as a more effective tool than illustration.

The post-test and interview analyses revealed that the students in the CAnI group experienced stronger conceptual change compared to the subjects in the CBI group. Although there are similarities in the interviewees' answers for both groups in the pre-test, the students in the CBI group consistently used the erroneous concepts that electrons flow through the electrolyte. They failed to mention that electrons were being transferred by redox reaction activities. Furthermore, the evidence showed that the interviewees in the CBI group simply memorized the sign of the electrodes based on the cathode electrode of the electrolytic cell as a point of reference to identify the sign of electrode for galvanic cells. They also believed that a salt bridge provides a pathway for the flow of electrons. It is suggested that subjects in CBI group experienced weak conceptual change as they failed to deeply understand the structure of the difficult concepts meaningfully. Perhaps, the CBI group's weak conceptual change is a consequence of surface understanding and over-simplification of information as commonly practiced by students when learning electrochemistry. However, the analyses demonstrated that the interviewees in the CBI groups had no problem in answering simple concepts of factual knowledge such as definitions of oxidation and reduction. In other words, CBI seems adequate to teach factual knowledge without involving complex, abstract and dynamic concepts.

Meanwhile, the answers given by the CAnI group in the post-test and during interviews showed a dramatic revision of their existing ideas. The answers to simple and difficult questions given by the interviewees in the CAnI group improved drastically and tended to follow a correct logical sequence of concepts, thus showing evidence of their strong conceptual change. For example, they referred to the conductivity of electrical current as a result of electrical charges carried by ions or as a result of oxidation and reduction processes. In explaining the complex, abstract and dynamic function of a salt bridge, they grasped the main idea that in a salt bridge, the electrolyte provides ions to migrate between the anode and cathode compartments, thus completing the circuit. They can express clear concepts of electrolytic and galvanic cells in comparison to the interviewees in the CBI group, suggesting deep learning had taken place. To sum up, it can clearly be suggested that the interviewees in the CAnI group acquired deeper understanding of complex, abstract and dynamic concepts than their counterpart in the CBI group. This is clear qualitative evidence that the CAnI approach fosters high order learning more successfully than the conventional CBI. The integration of animations in CAnI along with collective discussion to enhance the constructivist environment does result in more conceptual change. These findings clearly indicate that CAnI had positive effects on the subjects' performance especially for high cognitive post-test questions, supporting the assumption that CAnI enhance students' strong conceptual change as well as deeper understanding.

Although both groups claimed that the respective teaching methods were easy to comprehend and allow clear presentation, comparison does favor exposure to animation over the conventional direct transmission. The results revealed that the use of transparencies and animation both needed clearer explanation from the teacher. Both groups agreed that better explanation is crucial in improving the teachers' presentation. However, the main difference between the two is that the CAnI presentation appears superior at enabling students to imagine chemical processes and at the same time holding the students' focus. This suggests that animation presentation is an important factor in enhancing students' ability to visualize abstract and dynamic concepts, thus suggesting that animation incorporated in CAnI can serve as a tool for the visualizing of CAD concepts.

SUMMARY AND CONCLUSION TO PORTFOLIO

INTRODUCTION

The purpose of this chapter is to summarize the theoretical background used in this study and the conclusions of the quantitative and qualitative findings. This chapter summarizes the theoretical background, which addresses the way knowledge is constructed from the cognitive and social constructivist perspectives. This section is then followed by an overall conclusion of the study. Finally, recommendations for teaching practice and future research are proposed.

SUMMARY OF THEORETICAL BACKGROUND

The study was conducted based on cognitive and social constructivist perspectives, where learning is considered as an active process in which learners construct knowledge and make meaning through social interactions and experiences of the world around them. This means that there is information acquired by the students outside of, or in addition to, the formal scientific knowledge being taught to them. This information becomes part of the students' existing ideas that serve as a guide for them to make sense of new ideas.

Therefore, based on the theoretical background, knowledge construction is not just an accumulation of new facts but a process where learners make sense of new information by restructuring their existing ideas. Since students enter science lessons with their unique existing ideas, their interpretations often contradict new information under study. Therefore, it is crucial for teachers to take into account what their students already know about the topic to be taught and provide steps which could enhance conceptual change. It is argued that this can be done by a scaffolded instruction such as through computer animation which provides intelligible, plausible and fruitful learning materials.

The computer-animated instruction (CAnI) developed for this study to provide intelligible, plausible and fruitful learning materials has been utilized in three ways. Firstly, it served as a cognitive tool for identifying the students' existing knowledge as well as reconciling and developing new understandings through conceptual change. Secondly, it served as a social tool in promoting collective discussion, shared meaning and scaffolding for the understanding of new concepts, whilst at the same time increasing the students' focus and curiosity to learn. In constructivist classrooms, sharing and discussing personal understanding and interpretation of the subject matter through discussion are important (Weasenforth, Biensenbach-Lucas & Meloni, 2002)

Thirdly, it served as an instructional tool for resolving cognitive conflict by providing scaffolds and guidance to foster correct scientific concepts. The investigation of whether CAnI effectively enhanced conceptual change and therefore improved students' performances, relies on the findings of the quantitative and qualitative data. By combining both findings, the subjects' conceptual change and other related factors can be traced and highlighted.

CONCLUSIONS OF THE STUDY

The overall conclusion to this study can be summarized under the following sub-headings:

Conceptual Change

In the Malaysian context, students have learnt chemistry contents through an integrated science subject for at least eight years (from primary to lower secondary) and through a chemistry subject for two years (in upper secondary). Over this time, they have constructed their own complex existing ideas about chemistry concepts even with exposure to the same learning opportunities in the same classroom. Although not all new concepts can be understood by the students in the same way, the post-test answers and interview responses show that the subjects in the CAnI group experienced stronger conceptual change than the subjects in the CBI group. The answers given by the CAnI group in the post-test and during interviews showed a dramatic revision of their existing ideas, which provides evidence of their strong conceptual change. Furthermore, the subjects in the CAnI group who experienced stronger conceptual change were less likely to demonstrate misconceptions in the post-test than their counterparts in the CBI group.

This study also found at least three specific misconceptions demonstrated by the subjects from both the CAnI and CBI group, which can be added to the list of students' misconceptions documented in previous research. These misconceptions were found written by the students in the pre-test and post-test and detected during the interview sessions. These misconceptions were (a) a reducing agent is only in atomic form (b) there are positive atoms and negative atoms, and (c) in electrochemical cells, the cathode is always a negative electrode and the anode is always a positive electrode. Another common misconception held by the subjects was that they believed the salt bridge supplied electrons which flowed through electrolyte solutions as electrical current in order to complete the galvanic cell's electrical circuit. This is consistent with the findings of Sanger and Greenbowe (1997b). Based on the researcher's experience and reading, the answer to the purpose of a salt bridge, 'in order to complete the circuit', was probably repeated from similar statements found in most general chemistry textbooks.

The research process demonstrated that factual knowledge such as definition of terminologies can be remembered and understood easily by the students in CAnI and CBI. Some misconceptions about simple concepts can also be restructured and resolved through both instructional approaches. In other words, it seems adequate for the factual knowledge to be intelligible in order to facilitate weak conceptual change, regardless of the method of instruction. For example, by just memorizing the facts, the subjects might have been able to give a correct definition of electrolyte.

The findings showed that the subjects in both groups had little difficulty in answering factual questions. The interviews, however, revealed that even after instruction, some students possessed misconceptions of some difficult concepts. This was more evident in the CBI group in relation to answering post-test questions concerning (a) the determination of the cathode and the anode of galvanic cell, (b) the prediction of reactions occurring in the electrolytic cell which used concentrated solution or reactive electrodes and (c) the explanation of the function of the salt bridge. A comment on why these misconceptions were less amongst the CAnI group point to the greater efficacy of the teaching approach used with these students, which will be explained in the next section.

The overall findings show positive results for the effectiveness of CAnI to enhance students' conceptual change of electrochemistry. These findings revealed substantial support for the hypothesis of the study that CAnI was significantly better as an instructional strategy to enhance conceptual change compared to CBI. Therefore, engaging students in constructivist instructional activities and presenting explicit sequences of animations does seem effective in significantly improving students' conceptual change.

Computer-Animated Instruction (CAnI)

There are numerous approaches to successfully bring inquiry into science lessons. This study has found that through CAnI, which shows step-wise sequences of diagrams to illustrate complex, abstract and dynamic concepts of electrochemistry led to better conceptual change than through CBI. Most importantly, the study revealed that complex, abstract and dynamic concepts need more than just the conventional instructional method to ensure correct understanding and accurate conceptual grasp. The analysis of the post-test answers and the interview transcripts revealed that the subjects in the CAnI group held more correct and complete electrochemistry concepts compared to the CBI group. The correctness and completeness of the answers demonstrated by the subjects in the CAnI group strengthen the claim that they experienced stronger conceptual change. Furthermore, clear and precise step-by-step constructivist animation is useful for students with less existing knowledge to conceptualize difficult information. Such animation would also be useful in promoting quality argument during collective discussion. This is because animation has the ability to clarify difficult and abstract concepts in a more convincing way without complicated explanation. Therefore, it can be suggested that collective discussion, and the use of well-designed constructivist animations, as instructional intervention, as experienced by the CAnI group, seem to provide scaffolds, which enhanced the subjects' conceptual change.

The study revealed that students who received instruction using static illustrations written on transparencies were generally successful at answering the post-test and probing questions at surface understanding. They seemed to answer using over-generalized statements such as 'the purpose of salt bridge is to complete the circuit', and 'electrons can flow through electrolyte.' They used these statements to justify their answer without understanding the basis of the concepts or apply the concepts to inappropriate situations.

The perception of students towards CAnI, as evidenced by their general comments, was also positive. Overall responses to the open-ended questionnaire revealed that animation was accepted as a more plausible, intelligible and fruitful teaching and learning method. The CAnI group agreed that they could easily understand the concepts shown to them through animations and was much easier for them to make sense of the concepts. In this case, concepts are considered intelligible to students in the CAnI group when they can explain the concepts in their own words. Findings also suggested that CAnI has an advantage over CBI as a more fruitful presentation, which encourages the solving of problems in a variety of new situations and conditions.

Responses from the open-ended questionnaire revealed that one of the important features of the animations was their ability to systematically portray complex, abstract and dynamic concepts of molecular processes. It is worth mentioning that animations could serve as an alternative replacement to static illustrations printed on transparencies (or drawn on the whiteboard) as practiced in conventional instruction.

Although the effect of CAnI was only analyzed from the comparison of the pre-test and post-test and from the probing interview questions, the findings demonstrated that the CAnI group outperformed the CBI group, thus supporting a major hypothesis for this study: CAnI enhances students' conceptual change in electrochemistry.

In conclusion, the findings support the movement from direct transmission approach to teaching and learning to constructivist approach as encouraged by the MOE. However, factors such as exam-oriented culture, time-constraint and lack of training are often identified to discourage teachers in implementing constructivist approach. Therefore, the MOE should consider providing more training for teachers to develop their understanding and practices about the constructivist approach to teaching and learning with the support of computer application as well as reducing too much emphasis on direct transmission approach. This study has proved that constructivist can be implemented through different techniques; one of these is through CAnI, which is practically designed for science teachers to implement constructivist activities of teaching and learning both from cognitive and social perspectives. CAnI can be implemented at all levels of education, effective in engaging students in active learning environment, in small or big classrooms.

RECOMMENDATIONS FOR TEACHING PRACTICE AND FUTURE RESEARCH

No one is absolutely sure how computer-mediated instruction will drive the future direction of science education. So far, most recent research in science education (Albaloosi & Alkhalifa, 2002; Brown, 2002; Hakkarainen, 2003; Leung, 2003; Jimoyiannis & Komis, 2001; Michael, 2001; Milrad, 2002; Sung & Ou, 2002; Reid et al., 2003) have found that computer-mediated instruction had a positive impact on student's science learning. A consensual view from such research is that user-friendly computer technologies will gradually replace or at least complement the conventional direct transmission approaches, especially to cater to groups of students with diverse backgrounds, motivations, interests and learning styles.

Although the study has brought attention to the advantages of using animation in teaching scientific concepts, it should be noted that further research with longer instructional time and larger samples are recommended in order to explore possible strengthening findings. In addition, more topics in chemistry should also be covered. The implementation of computer animations across different science disciplines such as Physics and Biology would allow broader comment spanning different science domains.

In addition to the conceptual change approach used in this study, there are many other approaches of constructivist teaching in the area of science education such as cooperative learning, problem solving, group discussions, hands-on activities, concept mapping and problem-based approaches which can be integrated with computer technologies. This study has shown that combining clear and precise step-by-step constructivist animation with collective discussion has led to better conceptual change than through the conventional instruction. It is believed that other approaches of constructivist teaching in the area of science education can also be implemented in well-designed computer-mediated teaching activities.

Even though this study found the use of animation and collective discussion promising as part of constructivist instruction, CAnI, like other constructivist computer-mediated instruction, places specific requirements on teachers. On this basis, the potential of the computer as a constructivist instructional tool is unlikely to be fully utilized unless the science educators, when planning their lessons ensure that they:

1. represent subject contents that promote active knowledge construction;
2. structure teaching activities that probe students' current ideas;
3. structure teaching activities that allow them to examine their own ideas;
4. organize teaching activities that challenge students' understandings and resolve misconceptions;
5. create teaching activities that engage students on their current interests; and

6. encourage students' involvement in classroom discussion.

Therefore, future study is needed to examine the extent to which these strategies might be integrated and manipulated in computer-mediated instruction in order to enhance not only students' conceptual understanding but also their ability in other science process skills such as problem solving, scientific thinking, and critical thinking skills. More study is needed to determine the way of integrating and implementing such strategies in conventional classrooms and how they can cross subject discipline boundaries.

APPENDIX A: LESSON PLAN

<table>
<tr><td colspan="3">UNIT 1</td></tr>
<tr><td>Main Topics</td><td>At the end of this lesson, students should be able to:</td><td>Teaching aid / Activities</td></tr>
<tr><td>INTRODUCTION

• Reduction and oxidation

• Redox

• Oxidation and reduction agents

• Electrolyte

• Electrochemical Series (ES)

• Electrochemical Cells</td><td>a. define oxidation in terms of electron donation.

b. define reduction in terms of electron acceptance.

c. identify redox as interdependence of oxidation and reduction processes.

d. define and identify oxidizing agents.

e. define and identify reducing agents.

f. identify the species oxidized and reduced from a given redox equation.

g. write a balanced oxidation and reduction half-equation.

h. write a balanced overall redox reaction.

i. define electrolytes and give examples.

j. state that electrolytes consist of free ions.

k. interpret the Electrochemical Series with regard to:
▪ strong oxidation agent/reducing agent
▪ preferable for reduction/oxidation
▪ tendency for losing/gaining electrons

l. State that electrochemical cells can be divided into electrolytic and chemical cells

m. describe the construction of simple electrochemical cells.

n. state the basic differences of electrolytic and galvanic cells.</td><td><u>A. CAnI Method</u>

<u>Teaching Aids:</u>
1. Handout Unit 1
2. Computer – CAnI Unit 1
3. Data Projector / Screen

<u>Main Activities:</u>

1. Start with showing lesson screen and asking discrepant events or probing questions.
(Ask students to give their own views on specific concept).
2. Encourage collective discussion (Encourage discussion on the pros and cons of the answers)
3. Explain the fundamental concepts through animation. (Highlight the event or concept which is hard to understand during the discussion).
4. Guide the students to the correct answers through animation.
5. Sum-up the lesson

<u>B. CBI Method</u>

<u>Teaching Aids:</u>

1. Handout Unit 1
2. Transparencies Unit 1
3. OHP / Screen

<u>Main Activities:</u>

1. Explain the fundamental concepts and facts
2. Explain the meaning of the terminologies
3. Give examples
4. Question-answer session
5. Sum-up the lesson</td></tr>
</table>

APPENDIX A (continued)

UNIT 2		
Main Topics	At the end of this lesson, students should be able to:	Teaching aid / Activities
ELECTROLYTIC CELL ▪ Electrolyte cell of molten $PbBr_2$ ▪ Sodium Extraction Factor affecting electrolysis of aqueous solution ▪ Electrolytic cell using reactive electrode of $NiSO_4$ solution. ▪ Silver-plating	a. describe that electrolytic cell is involving the process of electrolysis in which electrical energy is used to produce chemical change. b. sketch and completely label a simple electrolytic cell. c. explain positive and negative terminal d. define the anode as electrode at which oxidation occurs. e. define the cathode as electrode at which reduction occurs. f. explain the operation of electrolytic cell using molten $PbBr_2$ with regard to: ▪ ions migration ▪ reaction occurs at the anode/cathode ▪ electron flow in the external circuit ▪ predict the products g. interpret and write a balance overall redox reaction. h. describe with diagram the extraction sodium using molten NaCl with regard to: • ions migration • the oxidation and reduction half-equations • predict the products • collect the products i. list the factors affecting electrolysis of aqueous solution that are • the Electrochemical Series • the concentration of the electrolyte • the nature of the electrodes j. explain the factors affecting electrolysis of aqueous solutions: ▪ dilute NaCl solution using inert electrodes ▪ concentrate NaCl solution using inert electrodes ▪ dilute NaCl solution using reactive electrodes k. explain the operation of electrolytic cell using aqueous solution of $NiSO_4$ with regard to: ▪ ions migration ▪ reaction occurs at the anode/cathode ▪ electron flow in the external circuit ▪ predict the products l. describe with diagram the process of electroplating using silver-plating as an example with regard to: ▪ ions migration ▪ reaction occurs at the anode/cathode ▪ electron flow in the external circuit ▪ predict the products	**<u>A. CAnI Method</u>** <u>Teaching Aids:</u> 1. Handout Unit 2 2. Computer – CAnI Unit 2 3. Data Projector / Screen <u>Main Activities:</u> 1. Start with showing lesson screen and asking discrepant events or probing questions. *(Ask students to give their own views on specific concept).* 2. Encourage collective discussion *(Encourage discussion on the pros and cons of the answers)* 3. Explain the fundamental concepts through animation. *(Highlight the event or concept which is hard to understand during the discussion).* 4. Guide the students to the correct answers through animation. 5. Sum-up the lesson **<u>B. CBI Method</u>** <u>Teaching Aids:</u> 1. Handout Unit 2 2. Transparencies Unit 2 3. OHP / Screen <u>Main Activities:</u> 1. Explain the fundamental concepts 2. Explain the meaning of the terminologies 3. Give examples 4. Question-answer session 5. Conclusion

APPENDIX A (continued)

<table>
<tr><th colspan="3">Unit 3</th></tr>
<tr><th>Main Topics</th><th>At the end of this lesson, students should be able to:</th><th>Teaching aid / Activities</th></tr>
<tr><td>CHEMICAL CELL (GALVANIC CELL)

• Introduction
• Spontaneous redox reaction

▪ Zn/Cu cell

▪ Dry cell</td><td>a. describe that chemical cell (galvanic cell) is a system transforming the chemical change of redox reactions to electrical energy.

b. sketch and completely label a simple galvanic cell.

c. analyse spontaneous redox reactions by using the Electrochemical Series.

d. use the Electrochemical Series to predict the preferable for oxidation and reduction.

e. explain the operation of chemical cell using Zn-Cu electrodes with regard to:
▪ spontaneous redox reaction
▪ reactions occur at the cathode and anode
▪ electron flow in the external circuit
▪ positively and negatively charged electrodes

6. the function of salt bridge

g. sketch and completely label a simple dry cell.</td><td><u>A: CAnI Method</u>

<u>Teaching Aid:</u>
1. Handout Unit 3
2. Computer – CAnI Unit 3
3. Data Projector
4. Screen

<u>Main Activities:</u>

1. Start with showing lesson screen and asking discrepant events or probing questions.
(Ask students to give their own views on specific concept).
2. Encourage collective discussion (Encourage discussion on the pros and cons of the answers)
3. Explain the fundamental concepts through animation. (Highlight the event or concept which is hard to understand during the discussion).
4. Guide the students to the correct answers through animation.
5. Sum-up the lesson

<u>B. CBI Method</u>

<u>Teaching Aid:</u>

1. Handout Unit 3
2. Transparencies Unit 3
3. OHP / Screen

<u>Main Activities:</u>
1. Explain the fundamental concepts
2. Explain the meaning of the terminologies
3. Give examples
4. Question-answer session
5. Conclusion</td></tr>
</table>

Continued next page

APPENDIX A (continued)

Unit 4		
Main Topics	At the end of this lesson, students should be able to:	Teaching aid / Activities
Summary of the lesson	a. analyze the relationship between electrolytic and galvanic cells. b. briefly explain the main differences between electrolytic cells and galvanic cells in terms of • the use of a spontaneous redox reaction to generate electricity • the use of electricity to drive non-spontaneous redox reaction • the flow of electrons • the reactions occur at the anode/cathode • the function of electrolyte or salt bridge • the electrical charge at the anode and the cathode	**A: CAnI Method** Teaching Aid: 1. Handout Unit 4 2. Computer – CAnI Unit 4 3. Data Projector 4. Screen Main Activities: 1. Start with showing lesson screen and asking discrepant events or probing questions. *(Ask students to give their own views on specific concept).* 2. Encourage collective discussion *(Encourage discussion on the pros and cons of the answers)* 3. Explain the fundamental concepts through animation. *(Highlight the event or concept which is hard to understand during the discussion).* 4. Guide the students to the correct answers through animation. 5. Sum-up the lesson **B. CBI Method** Teaching Aid: 1. Handout Unit 4 2. Transparencies Unit 4 3. OHP / Screen Main Activities: 1. Explain the fundamental concepts 2. Explain the meaning of the terminologies 3. Give examples 4. Question-answer session 5. Conclusion

APPENDIX B: POST-TEST

☑ The test is constructed to target fundamental understanding of electrochemistry.
☑ Read each question carefully.
☑ Write as much as you can, using all the time you have.

<u>Instruction</u>

- **Time: 40 Minutes**
- **This paper consists of Section A and Section B.**
- **Answer ALL QUESTIONS**

You can refer to the Electrochemical Series given below :

Preferable to gain electrons. Example: $Cl_2 + 2e \longrightarrow 2Cl^-$ (↑)

$$Cl_2 + 2e \rightleftharpoons 2Cl^-$$
$$O_2 + 4H^+ + 4e \rightleftharpoons 2H_20$$
$$NO_3^- + 2H^+ + e \rightleftharpoons NO_2 + H_20$$
$$Ag^+ + e \rightleftharpoons Ag$$
$$SO_4^{2-} + 4H^+ + e \rightleftharpoons H_2SO_3 + H_2O$$
$$O_2 + 2H_2O + 4e \rightleftharpoons 4OH^-$$
$$Cu^{2+} + 2e \rightleftharpoons Cu$$
$$2H^+ + 2e \rightleftharpoons H_2$$
$$Sn^{2+} + 2e \rightleftharpoons Sn$$
$$Ni^{2+} + 2e \rightleftharpoons Ni$$
$$Zn^{2+} + 2e \rightleftharpoons Zn$$
$$2H_2O + 2e \rightleftharpoons H_2 + 2OH^-$$
$$Na^+ + e \rightleftharpoons Na$$

Preferable to release loose electrons. Example: $Na \longrightarrow Na^+ + e$ (↓)

Section A

1. Define each of the following:
   a. Reduction (by electron transfer)
   b. Anode (2 Marks)

2. Choose the reducing agent and oxidizing agent in the following reaction:
   $Zn + Cu^{2+} \longrightarrow Zn^{2+} + Cu$

   (i) Reducing agent is ______(ii) Oxidizing agent is ______
   (1 Mark)

3. What allows the aqueous solution of $CuSO_4$ to conduct electrical current? Describe you answer.

(3 Marks)

4. Explain why the cathode in an electrolytic cell of molten $PbBr_2$ is negatively charged whilst the cathode in a galvanic cell of Zn-Cu is positively charged?

(2 Marks)

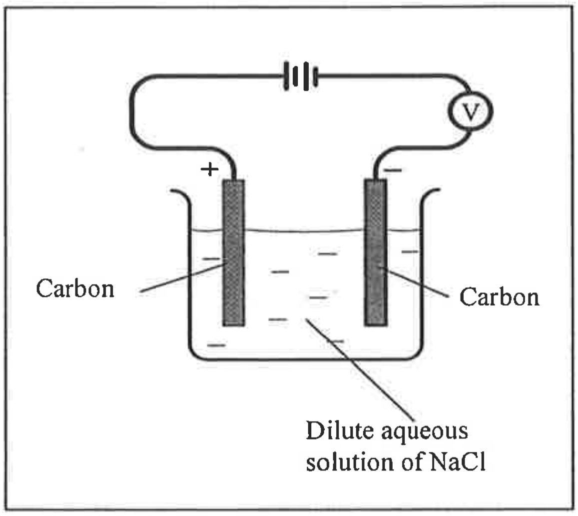
5. In a galvanic cell, is the more active (reactive) metal more likely to be the anode or the cathode? Briefly explain your opinion.

(2 Marks)

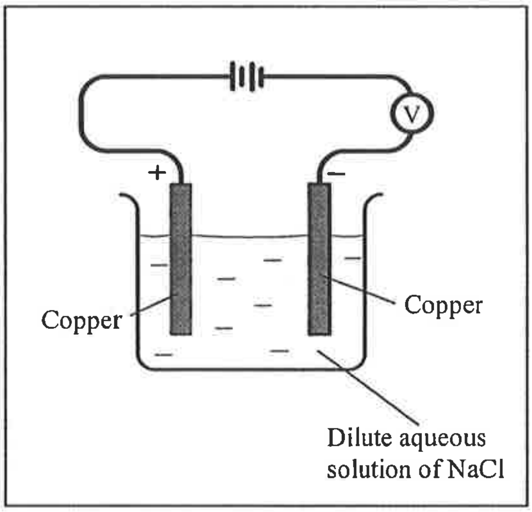
Section B

1. You are given two electrolytic cells, Cell P and Cell Q, as shown below:

Cell P



Cell Q



a. State (i) the reactions that occur at the anode and the cathode and (ii) the physical observations when electric current passes through each cell. Write your answer by completing the table below.

	Cathode		Anode	
	(i) Equation of the reaction	(ii) Observation	(i) Equation of the reaction	(ii) Observation
Cell P	$2H_2O + 2e \rightarrow H_2 + 2OH$	*Gas is liberated*		

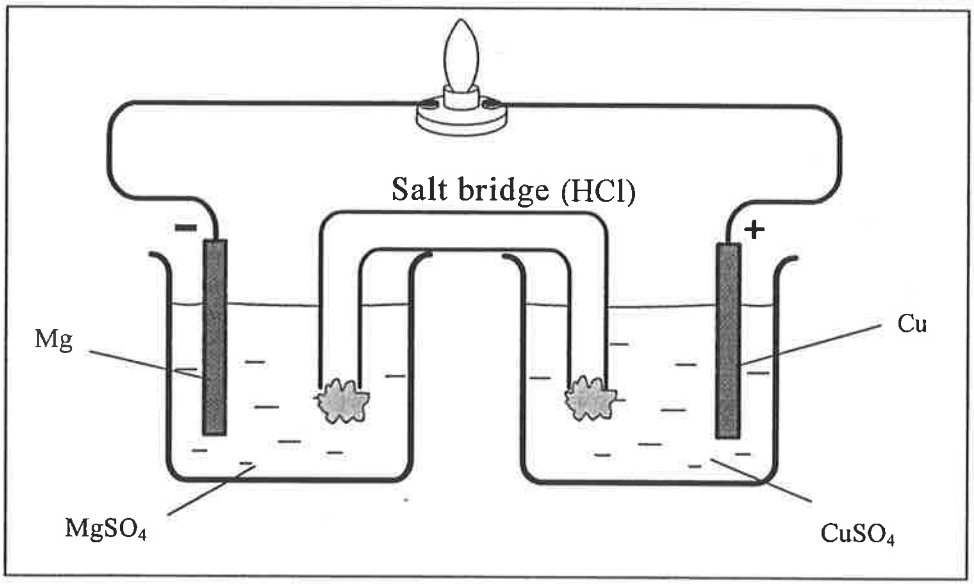
	Cathode		Anode	
	(i) Equation of the reaction	(ii) Observation	(i) Equation of the reaction	(ii) Observation
Cell Q				

(6 Marks)

b. In your opinion, which electrolytic cell is more suitable for electroplating - Cell P or Cell Q? Give your reasons.

(2 Marks)

2. A simple galvanic cell can be built as shown below. Both magnesium (Mg) and copper (Cu) electrodes are connected to the terminals of a low power light globe.



c. Explain what happens at the Mg electrode and Cu electrode when the cell is completed. Write the half-cell equation of the reactions at both electrodes.

(4 Marks)

d. Prepare the same galvanic cell by replacing HCl salt bridge with alcohol salt bridge. Predict what will happen to the lighting of the low power light globe compared the one that used HCl salt bridge. Give your reasons.

(3 Marks)

APPENDIX C: SUMMARY OF SHAPIRO- WILK 'S TEST.

Research Hypotheses	Dependent variables	Groups	Shapiro-Wilk		
			Statistic	df	Sig.
H_3 and H_4	Post-test	CAnI	.979	45	.582
	Post-test	CBI	.955	40	.116
H_5 and H_6	Post-test GQ	CAnI	.953	45	.067
	Post-test GQ	CBI	.963	40	.210
H_7 and H_8	Post-test SQ	CAnI	.961	45	.136
	Post-test SQ	CBI	.960	40	.169
H_9	Post-test	HA CAnI	.958	24	.408
	Post-test	HA CBI	.941	20	.250
H_{10}	Post-test	LA CAnI	.962	21	.550
	Post-test	LA CBI	.974	20	.831
H_{11}	Post-test GQ	HA CAnI	.932	24	.110
	Post-test GQ	HA CBI	.946	20	.314
H_{12}	Post-test GQ	LA CAnI	.961	21	.547
	Post-test GQ	LA CBI	.934	20	.182
H_{13}	Post-test SQ	HA CAnI	.953	24	.307
	Post-test SQ	HA CBI	.967	20	.701
H_{14}	Post-test SQ	LA CAnI	.954	21	.400
	Post-test SQ	LA CBI	.947	20	.325

Note. Abbreviations:

- LA indicates low achiever students.
- HA indicates higher achiever students.
- GQ indicates general question
- SQ indicates specific question

APPENDIX D: LEVENE'S TESTS

Levene's Test of Equality of Error Variances

Dependent Variable: Post-test

F	df1	df2	Sig.
.284	3	81	.837

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.
a Design: Intercept+PRE-TEST+METHOD+LEVEL+METHOD * LEVEL

Levene's Test of Equality of Error Variances

Dependent Variable: Post-test GQ

F	df1	df2	Sig.
.992	3	81	.401

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.
a Design: Intercept+METHOD+LEVEL+METHOD * LEVEL

Levene's Test of Equality of Error Variances

Dependent Variable: Post-test SQ

F	df1	df2	Sig.
.443	3	81	.723

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.
a Design: Intercept+PRE-TEST SQ+METHOD+LEVEL+METHOD * LEVEL

Levene's Test of Equality of Error Variances

Dependent Variable: Post-test

F	df1	df2	Sig.
.284	3	81	.837

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.
a Design: Intercept+PRE-TEST+GROUP

Levene's Test of Equality of Error Variances

Dependent Variable: Post-test GQ

F	df1	df2	Sig.
.992	3	81	.401

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.
a Design: Intercept+GROUP

Levene's Test of Equality of Error Variances

Dependent Variable: Post-test SQ

F	df1	df2	Sig.
.443	3	81	.723

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.
a Design: Intercept+PRE-TEST SQ+GROUP

APPENDIX E: SAPIRO-WILK'S TEST

Tests of Normality

	CAnl and CBII	Shapiro-Wilk		
		Statistic	df	Sig.
Posttest GQ	CBI	.963	40	.210
	CAnl	.953	45	.067
Posttest SQ	CBI	.960	40	.169
	CAnl	.961	45	.136
Posttest	CBI	.955	40	.116
	CAnl	.979	45	.582

* This is a lower bound of the true significance.

Tests of Normality (CBI High Achiever)

	Shapiro-Wilk		
	Statistic	df	Sig.
Posttest GQ	.946	20	.314
Posttest SQ	.967	20	.701
Posttest	.941	20	.250

* This is a lower bound of the true significance.

Tests of Normality (CBI Low Achiever)

	Shapiro-Wilk		
	Statistic	df	Sig.
Posttest GQ	.934	20	.182
Posttest SQ	.947	20	.325
Posttest	.974	20	.831

* This is a lower bound of the true significance.

Tests of Normality (CAnl High Achiever)

	Shapiro-Wilk		
	Statistic	df	Sig.
Posttest GQ	.932	24	.110
Posttest SQ	.953	24	.307
Posttest	.958	24	.408

* This is a lower bound of the true significance.

APPENDIX E (continued)

Tests of Normality (CAnI Low Achiever)

	Shapiro-Wilk		
	Statistic	df	Sig.
Posttest GQ	.961	21	.547
Posttest SQ	.954	21	.400
Posttest	.962	21	.550

* This is a lower bound of the true significance.

Tests of Normality (Pre-test Post-test)

Groups	Shapiro-Wilk		
	Statistic	df	Sig.
CBI	.973	40	.460
CAnI	.979	45	.586

* This is a lower bound of the true significance.

APPENDIX F: ASSUMPTION OF ANCOVA

Tests of Between-Subjects Effects

Dependent Variable: Post-test

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	463.530	6	77.255	6.387	.000
Intercept	2980.085	1	2980.085	246.374	.000
PRE-TEST	94.518	1	94.518	7.814	.007
METHOD	183.226	1	183.226	15.148	.000
LEVEL	26.351	1	26.351	2.179	.144
METHOD * PRE-TEST	23.675	1	23.675	1.957	.166
LEVEL * PRE-TEST	1.805	1	1.805	.149	.700
METHOD * LEVEL * PRE-TEST	8.017	1	8.017	.663	.418
Error	943.470	78	12.096		
Total	13647.000	85			
Corrected Total	1407.000	84			

a R Squared = .329 (Adjusted R Squared = .278)

Correlations

		Pre-test	Post-test
Pre-test	Pearson Correlation Sig. (2-tailed) N	1 . 85	.318 .003 85
Post-test	Pearson Correlation Sig. (2-tailed) N	.318 .003 85	1 . 85

** Correlation is significant at the 0.01 level (2-tailed).

Tests of Between-Subjects Effects

Dependent Variable: PostStest GQ

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	53.367	6	8.894	3.189	.007
Intercept	422.925	1	422.925	151.638	.000
METHOD	35.410	1	35.410	12.696	.001
LEVEL	.195	1	.195	.070	.792
PRE-TEST GQ	5.171	1	5.171	1.854	.177
METHOD*PRE-TEST GQ	12.541	1	12.541	4.496	.037
LEVEL*PRE-TEST GQ	1.642	1	1.642	.589	.445
METHOD * LEVEL * PRE-TEST GQ	3.241E-02	1	3.241E-02	.012	.914
Error	217.545	78	2.789		
Total	2272.750	85			
Corrected Total	270.912	84			

a R Squared = .197 (Adjusted R Squared = .135)

APPENDIX F (continued)

Correlations

		Pre-test GQ	PostStest GQ
Pre-test GQ	Pearson Correlation	1	.174
	Sig. (2-tailed)	.	.110
	N	85	85
Post-test GQ	Pearson Correlation	.174	1
	Sig. (2-tailed)	.110	.
	N	85	85

Tests of Between-Subjects Effects

Dependent Variable: Post-test SQ

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	233.006	6	38.834	5.175	.000
Intercept	1761.996	1	1761.996	234.794	.000
METHOD	72.293	1	72.293	9.633	.003
LEVEL	47.770	1	47.770	6.366	.014
PRE-TEST SQ	72.096	1	72.096	9.607	.003
METHOD * PRE-TEST SQ	.325	1	.325	.043	.836
LEVEL * PRE-TEST SQ	15.170	1	15.170	2.021	.159
METHOD * LEVEL * PRE-TEST SQ	22.624	1	22.624	3.015	.086
Error	585.347	78	7.504		
Total	5196.000	85			
Corrected Total	818.353	84			

a R Squared = .285 (Adjusted R Squared = .230)

Correlations

		Pre-test SQ	Post-test SQ
Pre-test SQ	Pearson Correlation	1	.273
	Sig. (2-tailed)	.	.011
	N	85	85
Post-test SQ	Pearson Correlation	.273	1
	Sig. (2-tailed)	.011	.
	N	85	85

* Correlation is significant at the 0.05 level (2-tailed).

Tests of Between-Subjects Effects

Dependent Variable: Post-test

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	464.562	7	66.366	5.422	.000
Intercept	2972.241	1	2972.241	242.841	.000
GROUP	203.729	3	67.910	5.548	.002
PRE-TEST	95.227	1	95.227	7.780	.007
GROUP * PRE-TEST	37.561	3	12.520	1.023	.387
Error	942.438	77	12.239		
Total	13647.000	85			
Corrected Total	1407.000	84			

a R Squared = .330 (Adjusted R Squared = .269)

APPENDIX F (continued)

Correlations

		Post-test	Pre-test
Post-test	Pearson Correlation	1	.318
	Sig. (2-tailed)	.	.003
	N	85	85
Pre-test	Pearson Correlation	.318	1
	Sig. (2-tailed)	.003	.
	N	85	85

** Correlation is significant at the 0.01 level (2-tailed).

Tests of Between-Subjects Effects

Dependent Variable: Post-test GQ

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	55.041	7	7.863	2.805	.012
Intercept	422.717	1	422.717	150.781	.000
GROUP	37.403	3	12.468	4.447	.006
PRE-TEST GQ	5.335	1	5.335	1.903	.172
GROUP * PRE-TEST GQ	17.354	3	5.785	2.063	.112
Error	215.871	77	2.804		
Total	2272.750	85			
Corrected Total	270.912	84			

a R Squared = .203 (Adjusted R Squared = .131)

Correlations

		Post-test GQ	Pre-test GQ
Post-test GQ	Pearson Correlation	1	.174
	Sig. (2-tailed)	.	.110
	N	85	85
Pre-test GQ	Pearson Correlation	.174	1
	Sig. (2-tailed)	.110	.
	N	85	85

Tests of Between-Subjects Effects

Dependent Variable: Post-test SQ

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	236.554	7	33.793	4.473	.000
Intercept	1765.452	1	1765.452	233.654	.000
GROUP	119.336	3	39.779	5.265	.002
PRE-TEST SQ	73.901	1	73.901	9.781	.002
GROUP * PRE-TEST SQ	35.019	3	11.673	1.545	.210
Error	581.798	77	7.556		
Total	5196.000	85			
Corrected Total	818.353	84			

a R Squared = .289 (Adjusted R Squared = .224)

Correlations

		Post-test SQ	Pre-test SQ
Post-test SQ	Pearson Correlation	1	.273
	Sig. (2-tailed)	.	.011
	N	85	85
Pre-test SQ	Pearson Correlation	.273	1
	Sig. (2-tailed)	.011	.
	N	85	85

* Correlation is significant at the 0.05 level (2-tailed).

APPENDIX G: PAIRED-SAMPLES STATISTICS FOR CAnI GROUP

Pair	Mean	N	Std. Deviation	Std. Error Mean
Pre-test	3.189	45	2.1487	.3203
Post-test	13.567	45	3.6285	.5409

Pair	N	Correlation	Sig.
Pre-test and Post-test	45	.183	.228

Pair	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Dev.	Std. Error Mean	95% Confidence Lower	95% Confidence Upper			
Pre-test and post-test	-10.378*	3.863	.576	-11.538	-9.217	-18.022	44	.000

*p < .05

APPENDIX H: PAIRED-SAMPLES STATISTICS FOR CBI GROUP

Pair 1	Mean	N	Std. Deviation	Std. Error Mean
Pre-test	3.325	40	2.7725	.4384
Post-test	10.238	40	3.8994	.6165

	N	Correlation	Sig.
Pre-test and Post-test	40	.507	.001

Pair	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Dev.	Std. Error Mean	95% Confidence Lower	95% Confidence Upper			
Pre-test and Post-test	-6.913*	3.453	.5459	-8.017	-5.808	-12.662	39	.000

*p < .05

APPENDIX I: INTERVIEW TRANSCRIPTS

Subject: Anna (Pseudonym)
Group: CBI
Avenue: Meeting Room, Matriculation Centre, IIU Malaysia
Time: 3.00 pm
Date: 22 December 2004

Artifacts of transcription:
[ ] : Comments inserted by researcher to clarify the discourse
.... : Pause / silent
R : Researcher
S : Subject

R: What made you choose oxidation as a process of gaining electron?
S: It's the redox reaction…
R: Why did you choose cathode as the negative pole?
S: I thought that cathode is negative…and anode is positive
R: Do you think that it's not correct?
S: Now I know it was wrong
R: Rewrite the equation.

S: $Zn + Cu^{2+} \rightarrow Zn^{2+} + Cu$
ox process; red process

R: Which is the reducing agent?
S: The reducing agent… it reduced others…Zn is the reducing agent.
R: What about the oxidizing agent?
S: It oxidized others…it is definitely copper
R: Write down your answer.
S: Zn is a reducing agent. Cu^{2+} is an oxidizing agent.
R: But why your answer is Cu?
S: I didn't realize that ion could be a reducing agent or an oxidizing agent.
R: Write down the decomposition equation of $PbBr_2$ molten.

S: $PbBr_2 \rightarrow Pb^{2+} + Br^-$
$CuSO_4 \rightarrow Cu^{2+} + SO_4^{2-}$

R: Is your equation balanced?
S: I think so…
R: Write the decomposition equation of copper sulphate.

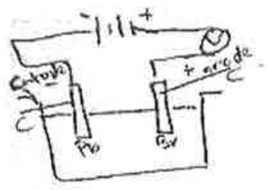
S: $CuSO_4 \rightarrow Cu^{2+} + SO_4^{2-}$

R: Which one is cation and which is anion?
S: Cation (Cu^{2+}) and anion (SO_4^-).
R: How do cation and anion transfer electricity?

APPENDIX I (continued)

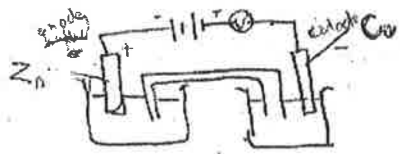
S: Through positive and negative charges.
R: Please explain further.
S: Emmm....it's quite difficult to explain.
R: Please draw an electrolytic cell of $PbBr_2$ molten.

S:



R: Now draw a galvanic cell using zinc and copper electrodes.

S:



R: Why is cathode (in electrolytic cell), a negative terminal?
S: It has many electrons.
R: How do you know that?
S: Electrons have negative charge.
R: What about the galvanic cell?
S: Emmm...I think it should be reversed.
R: Assuming that these are zinc and copper electrodes, what is the material for an electrode in electrolytic cell?
S: Carbon.
R: Which electrode is anode and which is cathode for a galvanic cell?
S: Since I think the zinc undergoes oxidation the Cu must be cathode
R: List down all the ions attracted to the cathode in cell Q.
S: Na^+
R: Can you predict the reaction?
S: Na produces Na^+

$$Na \longrightarrow Na^+ + e$$

R: From where do you think the bubbles come from?
S: I already wrote the answer.
R: Why did you choose cell Q for electroplating?
S: Just guessing.
R: Now predict the equation occurs at the cathode of cell Q.

S: $Cu^{2+} + 2e \longrightarrow 2Cu$

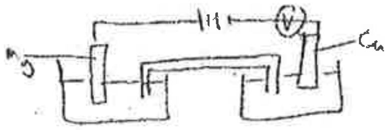
R: Do you think it is balanced?
S: I think so.

R: Why did you choose Cu^{2+}?
S: Copper receives electrons.
R: Where does the Cu^{2+} come from?
S: From the copper electrode.
R: Why is the color of the solution blue?
S: There are Cu^{2+} ions in the solution.
R: What is the equation that occur at the electrode anode of cell Q?

S: $Cu \longrightarrow Cu^{2+} + 2e$

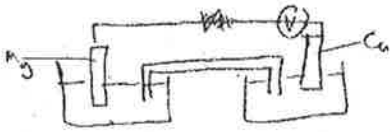
R: What do you think will happen when the copper electrode dissolve as ions?
S: I'm not sure.
R: Draw a galvanic cell using magnesium and copper electrodes.

S:



R: Do you think the battery is needed in the cell?

S: Oh. No, it's not needed.



R: Write the equations at both electrodes.
S:

$Mg^{2+} + 2e^- \longrightarrow Mg$ -- Reduc

$Cu \longrightarrow Cu^{2+} + 2e^-$ — Oxidation

R: Which do you think is the equation for reduction or oxidation?
S: Magnesium undergoes reduction and copper undergoes oxidation.
R: Could you explain more about it?
S: I don't think I can. I'm not very sure about it
R: What is the purpose of salt bridge?
S: To complete the cell.
R: Could you describe further?
S: It allows electrons to flow.
R: How is it so?
S: There is electricity.
R: What do you think will happen if alcohol is used instead of salt solution?
S: The light bulb will not light brightly

R: Why is this so?
S: Alcohol is a weak acid.

APPENDIX I (continued)

<u>Subject:Annie (Pseudonym)</u>
Group: CBI
Method: Clinical, IAI and IAE techniques
Avenue:Meeting Room, Matriculation Centre, IIU Malaysia
Time: 2.00 pm
Date: 24 December 2004

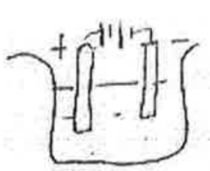
Artifacts of transcription:
[ ] : Comments inserted by researcher to clarify the discourse
.... : Pause / silent
R : Researcher
S : Subject

R: What do you mean by "oxidation number decreases"?
S: Because Cu^{2+} turns to Cu.
R: Rewrite the equation.

S: $Zn + Cu^{2+} \rightarrow Zn^{2+} + Cu$

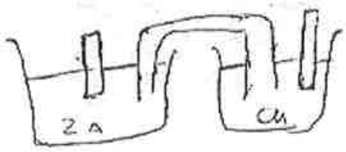
R: What is the relationship between the oxidation number and the oxidation process?
S: Gaining electrons...
R: Are you sure?
S: No...its losing electrons...
R: How do you know that Zn is a reducing agent?
S: Zinc releases electrons to form zinc ion, therefore zinc is a reducing agent
R: What about the oxidizing agent?
S: Its gains electrons....so copper ion is an oxidizing agent
R: What do you mean by "cathode is an electrode which attracts electron"?
S: [Silent]
R: How did you come up with the answer?
S: I imagined that the electrons were flowing...but I was not sure where they were moving to...
R: Could you write the decomposition equation of $PbBr_2$?
S:
$PbBr_2 \longrightarrow 2Pb^{2+} + Br^-$

R: What do you meant by 'the electrons move freely"?
Where do the electrons come from?
S: Bromine is negative....
R: What is the source of electron?
S: The plumbum...it releases electrons to bromine.
R: Draw an electrolytic cells of $PbBr_2$ molten.

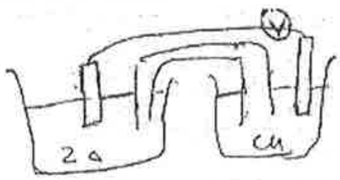
S:


APPENDIX I (continued)

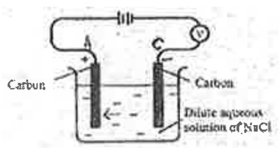
R: Which is the negative terminal and which is the positive terminal?
S: Cathode is the negative terminal and anode is the positive terminal
R: Why is cathode negative?
S: Because it is connected to the negative battery.....
R: Referring to your answer, what is the difference between free ions and free electrons?
S: Free ions.....(silent)
R: Which one is correct?
S: I am confused...
R: Electrons or ions? How are ions involved in electrical current?
S: When the positive ions and negative ions are attracted to the electrode....the electrical current is generated...
R: What actually id an electrical current?
S: [Silent]
R: Draw a galvanic cell using zinc and copper electrodes.

S: 

R: How does electricity flow in the cell?
S: There is a wire.



R: Why do you need a salt bridge?
S: To supply ionic charges...
R: Could you describe further?
S: To connect the solutions.
R: What will happen if there is no salt bridge?
S: Electrons cannot be transferred...
R: From which part of the cell is it transferred to?
S: From zinc to copper.
R: So, electrons can flow through the salt bridge?
S: No...
R: You said that electrons can flow from one solution to another through salt bridge.
S: [Silent]
R: Which electrode is anode and which is cathode for galvanic cell?
S: I'm not sure, I'm confused .
R: Which is anode and which is cathode for Cell P?

S: 

APPENDIX I (continued)

R: Why is cathode (C) negative and anode (A) positive?
S: It is opposite to the galvanic cell…
R: What about the galvanic cell?
S: Anode is negative, cathode is positive.
R: What made you say that cathode is negative (terminal) and anode is positive (terminal) for the electrolytic cell?
S: It flows electrons…
R: Which part flow electrons?
S: Aaaa….electrons flow from here to here (see arrow in Diagram). The electrode which releases electrons is called cathode.
R: What is the process that occurs at the cathode?
S: Oxidation.
R: Say that again?
S: Oxidation.
R: Actually the process is reduction. Why did you write Cl^{2+} is attracted to the positive electrode?

$$Cl^{2+} + 2e \longrightarrow Cl_2$$

S: Sorry…..chlorine is negative.
R: Rewrite the equation.

S: $Cl^{-} + 2e \longrightarrow Cl_2$

R: Is the equation correct?
S: Wait…I forgot the group of chlorine (in Periodic Table).
R: Anode is where the process of an oxidation occurs. Does your equation receive or release electrons?
S: Receives electron?
R: So, receiving electrons is a reduction not an oxidation. Rewrite you equation.

S: $2Cl^{-} + 2e \longrightarrow Cl_2$

R: How did you know that copper ions receive electrons at the electrode anode?
S: Because cathode and Cu^{2+} both are positively charged.
R: Why did you choose cell Q for electroplating?
S: Maybe the solution is more concentrated…
R: What made you say copper releases electrons?
S: I'm not really sure…I was just guessing.
R: You answer is "there is no electrons movement so, the globe will not light", why?
S: No electrons movement in the salt bridge.
R: What did you mean, electrons in the circuit or in the salt bridge?
S: I'm not sure…[silent]

APPENDIX I (continued)

Subject: Amy (Pseudonym)
Group: CBI
Avenue: Meeting Room, Matriculation Centre, IIU Malaysia
Time: 2.05 pm
Date: 23 December 2004

Artifacts of transcription:
[ ] : Comments inserted by researcher to clarify the discourse
.... : Pause / silent
R : Researcher
S : Subject

R: How did you know that oxidation is a process that release electrons?
S: I have learnt it in form 4 [secondary school].
R: What about cathode?
S: Yes…that too.
R: After attending the lesson, you chose anode as a positive electrode, why?
S: I don't remember…
R: What made you choose anode as a positive electrode?
S: I just exchanged it with the cathode…because cathode is negative
R: Please rewrite a redox equation of zinc and Cu^{2+} ?

$$Zn + Cu^{2+} \longrightarrow Zn^{2+} + Cu$$ S:

R: Which one is a reducing agent?
S: Zinc

reducing agent
↑
$$Zn + Cu^{2+} \longrightarrow Zn^{2+} + Cu$$

R: How do you know?
S: Firstly I determined which one has been reduced…it is Cu^{2+} to Cu
R: Can you explain?
S: Because the oxidation number has decreased.
R: Please explain.
S: Definitely the process of reduction.
R: What does it mean by the decreasing of oxidation number?
S: From 2+ to zero….
R: So…
S: This means that the zinc is reduced….so, zinc is the agent…
R: When Cu^{2+} is reduced, the reducing agent is zinc. What happen to zinc?
S: Zinc undergoes oxidation...
R: So which is the oxidizing agent?
S: Copper.
R: Show it in the equation.

APPENDIX I (continued)

S: Here it is…

reducing agent

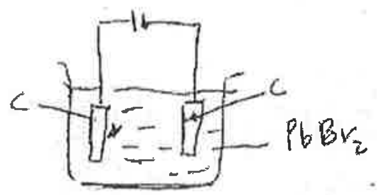
$$Zn + Cu^{2+} \longrightarrow Zn^{2+} + Cu$$

R: Is cooper a form of ion or atom?
S: Copper ion.
R: But your answer is copper atom?
S: I' m not very certain at that time…
R: Please write a decomposition equation of $CuSO_4$

$$CuSO_4 \longrightarrow Cu^{2+} + SO_4^{2-}$$ S:

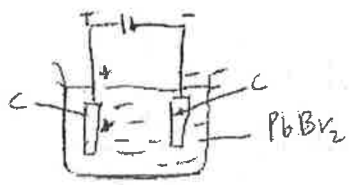
R: What is the connection between the equation and free ions?
S: (Silent)
R: Which are the free ions in the equation?
S: Here is anion (SO_4^{2-}) and here is cation (Cu^{2+})
R: Please draw an electrolytic cell of $PbBr_2$ molten, using carbon electrode?

S:



R: Which is the negative terminal and which is the positive terminal?

S:

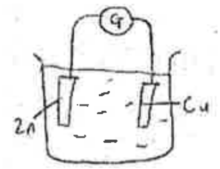


R: Which is the anode and which is the cathode?
S: This is cathode because it is negative.
R: Anode?
S: Anode is the positive electrode…
R: Why is anode a positive electrode ?
S: Because it is connected to the battery…
R: Can you explain?
S: Because the battery has the positive and negative sign…
R: Why the positive and negative sign?
S: Negative sign shows that there is an electrolyte in the battery…
R: What about the positive sign?
S: I don't know…
R: Why does the negative terminal become cathode electrode?
S: Because I remembered that cathode is negative and anode is positive…

APPENDIX I (continued)

R: Please draw a galvanic cell (chemical cell) using zinc and copper electrode.

S:



R: How do you know that this is a galvanic cell?
S: Because it has a galvanometer...the galvanic cell doesn't need batteries...it needs a Galvanometer...
R: What is the difference between a galvanic ce ll and anelectrolytic cell?
S: This one (electrolytic cell) is connected to an electrical source....this one (galvanic cell) uses chemical energy...
R: Where does the chemical energy comes from?
S: From moving electrons...
R: Where do the electrons come from?
S: From the zinc...

R: Write down the equation involved... S:

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

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

R: What about the salt bridge?
S: Opss....I forgot!
R: Why does Zn^{2+} undergo reduction and Cu undergo oxidation?
S: I m not sure...
R: Which electrode is anode and which is cathode?
S: Copper is anode.
R: Why?
S: Anode is the positive electrode.
R: How did you come up with this equation?

$$2H_2O + 2e \longrightarrow H_2 + 20H^-$$

S: From the Electrochemical Series......it looks familiar....
R: What has happened to the anode in cell Q?
S: [Silent]
R: What is you prediction?
S: The anode eroded....
R: How does it happen?
S: [Silent]
R: Has it dissolved or eroded?
S: I don't know
R: Why did you choose cell Q for electroplating?
S: Because it is suitable for electroplating...
R: Could you explain?

APPENDIX I (continued)

S: For electroplating, it must have precipitation...
R: Why do you say that Cu $^{2+}$ is reduced and Mg is oxidized?
S: Mg is above copper in the electrochemical series...Mg is more electropositive and easier to oxidized.
R: What is the function of salt bridge?
S: To complete the circuit.
R: How does it complete the circuit?
S: It has free ions...so it completes the circuit.
R: How do the free ions complete the circuit?
S: Huh...
R: What will happen if alcohol is used instead of salt solution?
S: The globe will not light up.
R: Why?
S: Because alcohol is a covalent molecule.
R: What do you mean by this?
S: There are no free ions.
R: How do the free ions work?
S: I don't know.
R: That's all. Thank you.

Subject: Sarah (Pseudonym)
Group: CAnI
Avenue: Meeting Room, Matriculation Centre, IIU Malaysia
Time: 3.00 pm
Date: 23 December 2003

Artifacts of transcription:
[ ] : Comments inserted by researcher to clarify the discourse
.... : Pause / silent
R : Researcher
S : Subject

R: What did you mean that oxidation is a process when electron is preferable to release electron?
S: Yes...it is a process to release electron.
R: What did you mean that cathode is receiving the anion [negative ion]?
S: Because cathode is negative....
R: Rewrite the equation for this question.
S:

$$Zn + Cu^{2+} \rightarrow Zn^{2+} + Cu$$

R: How do you determine a reducing agent?
S: Reducing agent...undergoes the oxidation process
R: So, which one is the reactant which undergo oxidation?
S: The reactant which releases electrons...

APPENDIX I (continued)

R: Write down the equation

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

R: The other one.

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

R: Please circle the reducing agent.

S: Definitely zinc [Zn].

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

R: Which one undergoes reduction reaction?

S: Copper ion…

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

R: What did you mean by your answer?

S: Copper sulphate is an ionic compound, so it conducts electricity in aqueous solution….

R: How?

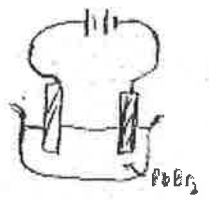
S: When dissolved, solution got anions and cations…they have charges…

R: Could you elaborate further.

S: Oxidation and reduction produce electrons to produce current…

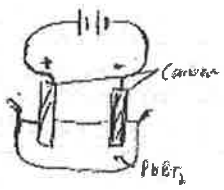
R: Draw an electrolytic cell of plumbum bromide molten.

S:



R: Which is positive electrode and negative electrode?

S:



R: What made you choose the electrode as negative electrode?

S: It is connected to the battery…which flow charges.

R: The battery flow charges?

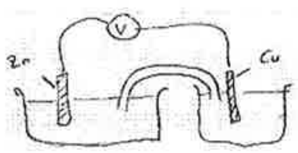
S: The battery flow the electrons….then…bromine receives the electrons

R: From where does bromine receive electrons?

S: It receives electrons from the battery….

R: Draw a galvanic cell using zinc and copper electrode.

S:



APPENDIX I (continued)

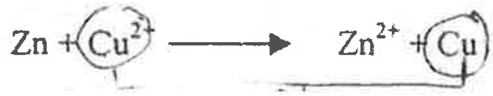
R: What is this?
S: Galvanometer…
R: What is the purpose of the Galvanometer?
S: To show whether the voltmeter increases or decreases.
R: Why increase and decrease?
S: It increases at the beginning of the reaction and then slowly decreases….
R: What happen when it increases?
S: Reaction occurs…then electrons flow.
R: How does the electrons flow?
S: Emmmm…..
R: Which is anode?
S: Zn….Zn more reactive
R: Is this you salt bridge?
S: Yes.
R: What is the purpose of the salt bridge?
S: To balance the electrons' charges.
R: What is the charge of electron?
S: [Silent]
R: What happens if the cell does not have a salt bridge?
S: The galvanic cell will undergo the electrolysis process.
R: Why did you choose Na involved at the anode in cell P ?
S: Na is reactive, easy to react.
R: Where did Na come from?
S: From solution…I guess.
R: Why did you choose cell Q for electroplating?
S: Because we can produce pure copper.
R: What happen to magnesium electrode?
S: It released ions.
R: Why did you choose magnesium (to release ions) instead of copper?
S: Because magnesium is more reactive than copper.
R: What did you mean?
S: Magnesium release ions faster than copper.
R: Release ions or electrons?
S: Electrons.
R: What will happen if alcohol is used as a salt bridge?
S: The light bulb will light brighter
R: Why?
S: Maybe…alcohol releases more ions
R: T hanks.

APPENDIX I (continued)

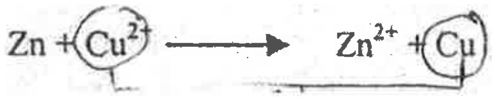
<u>Subject: Sally (Pseudonym)</u>
Group: CAnI
Avenue: Meeting Room, Matriculation Centre, IIU Malaysia
Time: 3.09 pm
Date: 24 December 2004

Artifacts of transcription:
[ ] : Comments inserted by researcher to clarify the discourse
.... : Pause / silent
R : Researcher
S : Subject

R: Explain the difference in your definition of reduction and oxidation in pre-test and post-test.
S: I'm not sure if it gain or lose electron...then I know...
R: How about cathode?
S: Initially I thought cathode was negative...I thought the answer was correct.
R: Please rewrite a redox equation in which Zn turns to Zn^{2+} and Cu^{2+} turns to Cu?
S:



R: Which one is a reducing agent?
S: First, I noticed ...Cu^{2+} to Cu...reduction.
R: How do you know it's a reduction?
S: Because...it receives electrons...
R: Please explain further.
S: It (Cu^{2+}) receives electron...
R: From which source?
S: Zinc metal...so reduction agent is zinc
R: What about zinc?
S: Zinc....oxidation process.....copper....reduction agent.
R: Which 'copper' did you mean according to your equation?
S: This one ...



R: How about the other one?
S: Copper ion...

R: Which one is correct?
S: Cu^{2+}
R: Why?
S: The reduction of oxidation number...
R: Please explain.
S: Reduction process...so it's oxidation agent....
R: Please write down the ionization equations for $PbBr_2$ and $CuSO_4$.

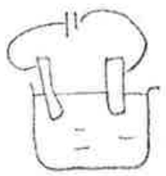
APPENDIX I (continued)

S: Both of them? (Refer to Equation 2 and Equation 3)

$$CuSO_4 \rightarrow Cu^{2+} + SO_4^{2-}$$

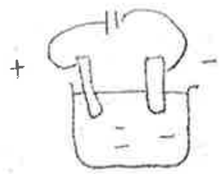
$$PbBr_2 \rightarrow Pb^{+2} + 2Br^{-}$$

R: Why did you write $O_4{}^{2-}$ and Br^{2-} as your pre-test's and post-test's answer?
S: I'm not good at writing chemical equation….I was wrong.
R: So how does the electrolytes conduct electrical current?
S: Reaction amongst ions occurred at the anode and the cathode…..positive ions and negative ions moved toward terminals with opposite charge, so it changed to electrical current….is it correct?
R: Can you elaborate further?
S: That's all I remember…
R: Please draw a simple electrolytic cell of $PbBr_2$ using carbon electrode.
S:



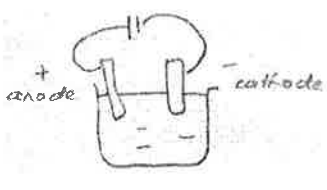
R: Which is negative terminal and positive terminal?

S: Here [see diagram below].

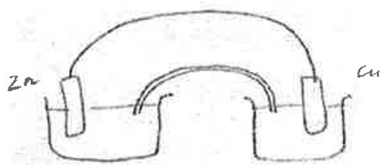


R: Which is the anode and the cathode?

S:



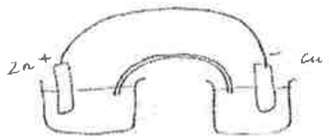
R: Why electrode cathode is negative?
S: Because it receives electrons from the battery…
R: How about galvanic cell? Please draw Zn-Cu galvanic cell.
S:



APPENDIX I (continued)

R: Please label the cathode and the anode.

S:



R: Why does Zn have positive charge?
S: Electrons were released…
R: Could you write down the equation.
S: $Zn + 2e \longrightarrow Zn^{2+}$
$Cu^{2+} \longrightarrow Cu + 2e$
R: Why did you choose Zn^{2+} releasing electrons and Cu receiving electron?
S: Zinc is located at a higher position in the electrochemical series…so zinc is electropositive….
R: Please explain your answer, why reactive metal tend to be an anode?
S: Reactive metal…more electropositive…
R: So what?
S: It tends to release electrons…
R: So what?
S: Wait…donate means oxidation…oxidation means anode…
R: Is your equation correct?
S: I'm not sure…

$2Cl^{-} + 2e \rightarrow Cl_2$

R: Can negative chloride, receive electron?
S: I'm not good at [chemical] equation…
R: What is happening at the cathode electrode in cell Q?
S: The precipitation of copper…
R: Are you sure?
S: I remembered one was eroded…one was precipitated
R: Why did you choose cell Q for electroplating?
S: We should use reactive electrode for electroplating…
R: Please explain.
S: There must be one electrode being eroded and as well as precipitated.
R: Why you did choose Mg undergoes oxidation?
S: Based on the position of Mg [located above Cu] in the Electrochemical series.
R: What is the function of salt bridge?
S: To complete the circuit….
R: How does salt bridge complete the circuit?
S: It has positive and negative ions…to balance the charges
R: Why did you think that the bulb light up?
S: Alcohol releases more ions.

APPENDIX I (continued)

R: What did you mean by alcohol has more ions or charges?
S: Ions have positive and negative charge…
R: Can you explain?
S: That all I know…
R: Is alcohol suitable for salt bridge, why?
S: I don't know about alcohol, so I'm just guessing
R: Thank you.

Subject: Sofia (Pseudonym)
Group: CAnI
Avenue: Meeting Room, Matriculation Centre, IIU Malaysia
Time: 2.00 pm
Date: 25 December 2004

Artifacts of transcription:
[ ] : Comments inserted by researcher to clarify the discourse
…. : Pause / silent
R : Researcher
S : Subject

R: Based on your pre-test answer, how did you know that 'oxidation is a process of releasing electrons to increase the oxidation number'?
S: I still remembered …
R: What did you mean cathode is a process of 'receiving anion'?
S: Definitely cathode receive anion…
R: Anion is negative ion, isn't it?
S: So, the cathode [negatively charged], attracts negative ions
R: Rewrite the redox equation.

S:

$$Zn + Cu^{2+} \longrightarrow Zn^{2+} + Cu$$

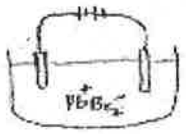
R: Which one is reduction agent?
S: Zinc.
R: How do you know?
S: From oxidation process
R: Please explain.
S: The oxidation number increase.
R: Oxidizing agent?
S: Copper.
R: Copper ion or copper atom?
S: Copper ion…
R: Write the ionization equation for copper sulphate and plumbum bromide.
S:

$$CuSO_4 \longrightarrow Cu^{2+} + SO_4^{2-}$$

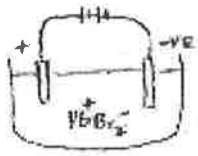
$$PbBr_2 \longrightarrow Pb^{2+} + 2Br^{-}$$

APPENDIX I (continued)

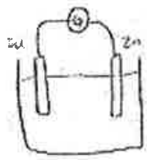
R: Where are free ions in your equation?
S: In the solution…..
R: I meant in the equation.
S: Where are they?
R: OK, what did you mean that ions produce electrical current?
S: Because ion got charges. These charges produced electrical current.
R: How is it that electrical current was produced?
S: I'm not sure.
R: Draw an electrolytic cell of $PbBr_2$ molten.
S:



R: Which one is negative terminal?
S:

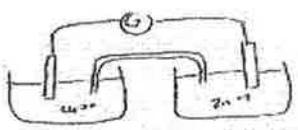


R: Why?
S: Because it is connected to battery's negative terminal.
R: Can you explain?
S: I have learnt it that way.
R: Draw a galvanic cell using zinc and copper as electrodes.
S:

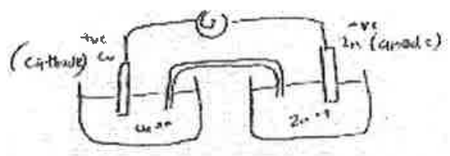


R: What is the difference compared to electrolysis cell?
S: We use Galvanometer not battery.
R: Where is your salt bridge? Redraw you diagram.

S:



R: Which one is anode and which one is cathode?
S: This one and this one [See Diagram below]



R: Write down the equation.

S:

$$Zn \longrightarrow Zn^{2+} + 2e$$

$$Cu^{2+} + 2e \longrightarrow Cu$$

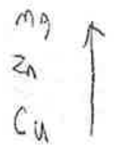
APPENDIX I (continued)

R: Which substance undergoes oxidation?

S: Zinc.

R: Why?

S: Zinc is located above copper in the Series of Electrochemistry



R: What does it means?

S: Zinc is more reactive

R: So?

S: Zinc is a reduction agent, it becomes Zn^{2+}

R: What if magnesium is being compared to zinc?

S: Magnesium will be positive.

R: Why does anode have negative charge?

S: Because the electrons accumulate there. Zinc releases the electrons.

R: What is the purpose of salt bridge?

S: To complete the circuit.

R: Could we replace it with wire?

S: No, because salt bridge maintains the ions.

R: Which one is the anode in cell P?

S: Anode has positive charge.

R: If anode is positive, how could it attract natrium ions?

S: I was wrong…

R: Could natrium ions react?

S: No, because the ions are not stable.

R: Why the ions are not stable?

S: As far as I'm concern, natrium is not stable.

R: Why?

S: Its configuration is not stable.

R: What configuration?

S: [Silent]

R: Why did you think water react at the cathode of cell Q?

S: Because it prefer to gain electrons compare to Na+

R: How did you know?

S: Here, from the Electrochemical Series

R: Why did you choose cell Q?

S: Not really sure.

R: Why did you choose magnesium undergoes oxidation?

S: Because it is located above the series of electrochemistry.

R: Why is it that the bulb will light if we used alcohol?

S: Alcohol is covalent molecule that has more ions such as CH_3COOH.

I: What is CH_3COOH?

S: Methanol.

APPENDIX J: SCORES

CBI Group (High achiever Students)

	Chemistry Grade	Pre-test Section A	Pre-test Section B	Pre-test	Post-test Section A	Post-test Section B	Post-test
1	4	1.5	1	2.5	4.5	10	14.5
2	3	2	1	3	4	7	11
3	4	1.5	1	2.5	5	7	12
4	4	0	0	0	4	5	9
5	3	1	0	1	3	4	7
6	3	2.5	0	2.5	4	5	9
7	1	2	3	5	4	3	7
8	1	2.5	0	2.5	7	9	16
9	3	3	3	6	5.5	11	16.5
10	4	2	1	3	5	3	8
11	4	0.5	2	2.5	4	6	10
12	1	3.5	1	2.5	7	8	15
13	3	3	0	3	7	9	16
14	2	4	8	12	6	10	16
15	3	1	0	1	1	2	3
16	2	1.5	3	4.5	5	7	12
17	3	1	1	2	2	4	6
18	4	2.5	0	2.5	3.5	6	9.5
19	4	1.5	1	2.5	5	5	10
20	3	1.5	3	4.5	4.5	12	15.5

CBI Group (Low achiever Subjects)

	Chemistry Grade	Pre-test Section A	Pre-test Section B	Pre-test	Post-test Section A	Post-test Section B	Post-test
1	5	2	2	4	2	4	6
2	5	1.5	0	1.5	5	2	7
3	5	1	0	1	3	3	6
4	6	1.5	2	3.5	3	3	6
5	5	0	2	2	4.5	1	5.5
6	5	1	5	6	4.5	10	14.5
7	5	3	1	4	4	6	10
8	6	2.5	4	6.5	7	2	9
9	5	1	0	1	2.5	4	6.5
10	6	0	0	0	2	1	3
11	5	1	2	3	2.5	5	7.5
12	2	3	8	11	5	11	16
13	6	0	0	0	4	5	9
14	5	0.5	1	1.5	3	8	11
15	6	0.5	2	2.5	6.5	7	13.5
16	5	1	1	1	3	5	8
17	5	1	0	1	3	6	9
18	5	1.5	9	10.5	6	5	11
19	5	1	4	5	4.5	12	16.5
20	5	1	1	2	4	8	12

APPENDIX J (continued)

CAnI Group (High achiever Students)

	Chemistry Grade	Pre-test Section A	Pre-test Section B	Pre-test	Post-test Section A	Post-test Section B	Post-test
1	3	2	0	2	8	11	19
2	4	1	2	3	5	11	16
3	3	4	6	10	5	12	17
4	1	3	3	6	6	5	11
5	2	2	2	4	6	12	18
6	4	2	2	4	4	5	9
7	3	3	2	5	7	7	14
8	2	2	1	3	6	8	14
9	4	1.5	2	3.5	0	3.5	3.5
10	2	0.5	6	6.5	6.5	5	11.5
11	3	4	1	5	4	7	11
12	3	3	2	5	6	17	23
13	2	0.5	3	3.5	6	11	17
14	4	3.5	3	6.5	3.5	9	12.5
15	4	2	0	2	8	10	18
16	3	2.5	3	5.5	7	8	15
17	2	1	2	3	6	6	12
18	4	1.5	1	2.5	3.5	8	11.5
19	4	0	0	0	6	6	14
20	3	1.5	5	6.5	7.5	10	17.5
21	4	2	2	4	5	10	15
22	2	2	0	2	7	8	15
23	3	1.5	0	1.5	3.5	11	14.5
24	4	3	0	3	6	8	14

APPENDIX J (continued)

CAnI Group (Low achiever Students)

	Chemistry Grade	Pre-test Section A	Pre-test Section B	Pre-test	Post-test Section A	Post-test Section B	Post-test
1	5	0.5	2	2.5	9	9	18
2	5	1	0	1	8	5	13
3	6	0	0	0	6.5	7	13.5
4	5	1	4	5	4.5	11	15.5
5	6	0	3	3	5	10	15
6	6	0	0	0	7	7	14
7	5	0.5	0	0.5	3.5	4	7.5
8	6	2.5	2	4.5	1.5	5	6.5
9	5	0.5	0	0.5	7	7	14
10	6	1.5	0	1.5	6	5	11
11	6	3	2	5	6	12	18
12	5	1.5	4	5.5	7	7	14
13	6	1	2	3	6	10	16
14	5	2	0	2	6	2	8
15	5	0.5	0	0.5	3.5	5	8.5
16	5	0.5	0	0.5	1.5	10	11.5
17	5	0.5	2	2.5	3.5	8	11.5
18	5	1	3	4	3	10	13
19	7	0.5	1	1.5	4	8	12
20	5	1	1	2	6	10	16
21	5	0.5	1	1.5	5.5	7	12.5

BIBLIOGRAPHY

Abas, Z. W. (1992). Komputer dalam pendidikan [Computer in education] Kuala Lumpur: Fajar Bakti.

Abdul Murad, M. H. S. (2004, October). *Science and Mathematics education in the new era - Challenges ahead.* Paper presented at the National Conference on Science and Mathematics Education, Kota Bharu, Kelantan.

Abdul Samad, A. (2003, October). *English as a tool for science and technology knowledge acquisition: Bilingual assessment instruments as a transitional measure.* Paper presented at the International Association of Education Assessment Conference, Manchester, London.

Adam, A. D. (2001, March). *Analysis of alternative conceptions in Physics and Biology: Similarities, differences, and implications for conceptual change.* Paper Presented at The Annual Meeting of the National Association for Research in Science Teaching, St. Louis, Missouri.

Albaloosi, F. & Alkhalifa, E. M. (2002). Multimedia as a cognitive tool. *Educational Technology & Society,* 5(4), 1-11.

Allendoerfer, R. D. (2003). KinSimXP, a chemical included in advanced chemistry simulation. *Journal of Chemical Education,* 80(1), 110-115.

Ainley, J., Banks, D., & Fleming, M (2002). The influence of IT: Perspective from five Australian schools. *Journal of Computer Assisted Learning,* 18, 395-404.

Anderson, L. W., & Krathwohl, D. R., (2001). *A Taxonomy for learning, teaching, and assessing: A revision of Bloom's Taxonomy of educational objectives*. New York: Longman.

Anastasi. A. (1988). *Psychological testing*. New York: MacMillan.

Ausubel, D. P. (1968). *Educational psychology: A cognitive view*. New York: Holt, Rinehart & Winston.

Ausuble, D. P., Novak, J. D., & Hanesian, H. (1978). *Educational psychologist: A cognitive view*. New York: Rinehart & Winston.

Azzarito, L., & Ennis, C. D. (2003). A sense of connection: Toward social constructivist physical education. *Sport, Education & Society,* 8(2), 179-188.

Bailey, P. D., & Garratt, J. (2002). Chemical education: Theory and practice. *University Chemistry Education,* 6, 39-57.

Barnett, M., Keating, T., Barab, S. A., & Hay, K. E. (2000). Conceptual change through building three-dimensional virtual models. In B. Fishman & O'Connors-Divelbiss (Eds.), *Fourth International Conference of the Learning Sciences* (pp. 134-141). New Jersey: Erlbaum.

Bartsch, R. A., & Cobern, K. M.(2003). Effectiveness of PowerPoint presentations in lectures. *Computers and Education,* 41(1), 77-87.

Basile, A., & D'Aquila, J. M.(2002). An experimental analysis of computer-mediated instruction and student attitudes in a principle of financial accounting Course. *Journal of Education for Business,* 77(3), 137-144.

Beeth, M. E., & Hennessy, M. G. (1996, April). *Teaching for cConceptual change in science: What counts as change?* Paper presented at the Annual Meeting of the National Association for Research in Science Teaching, St. Louis, MO.

Bell, B., Osborne, R., & Tasker, R. (1985). Appendix A: Finding out what children think. In R. Osborne & P. Freyberg (Eds.), *Learning in Science: The implications of children's science* (pp. 151-165). London: Heinemann.

Bell, R.L., Blair, L. M., Crawford, B. A., & Lederman, N. G. (2003). Just do it? Impact of science apprenticeship program on high school students' understandings of the nature of science and science inquiry. *Journal of Research in Science Teaching*, 40(5), 487-509.

Berg, B. L. (2001). *Qualitative research methods for the social sciences.* Boston: Allyn and Bacon.

Blank, L. M. (2000). A metacognitive learning cycle: A better warranty for student understanding? *Science Education,* 84, 486-506.

Bloom, B. S., Englehart, M. D., Hill, W. H., & Krathwohl, D. R. (1956). *Taxonomy of educational objectives: The classification of educational goals. Handbook I: Cognitive domain.* New York: McKay.

Bogdan, R. C., & S. K. Biklen (1998). *Qualitative research for education.* Boston: Allyn and Bacon.

Borg, W. R., & Gall, M. D. (1996). *Educational research: An introduction.* New York: Longman.

Brandt, W., & Rymenans, R. (2000). Recruitment of educational personnel. Geneva: ILO / UNESCO.

Brown, G., & Desforges, C. (1979). *Piaget's theory : A psychological critique.* London: Routledge & Kegan Paul.

Brown, R. F. (2002). Automated tutorial and assignment assessment. *Educational Technology & Society,* 5(1), 1-5.

Brooks, J.G. and Brooks, M.G. (1993). In search of understanding: The case for constructivist classrooms. Alexandria, VA: Association for Supervision and Curriculum Development. In Ministry of Education (2001) *Pembelajaran secara konstruktivisme* [Learning through constructivism]. Kuala Lumpur: Curriculum Development Center.

Bruner, J. (1985). Vygotsky: A historical and conceptual perspective. In J. V. Wertsch (Ed.), *Culture, communication, and cognition* (pp. 21 - 34). Cambridge: Cambridge University Press.

Burke, K. A., Greenbowe, T.J., & Windschitl, M. (1998). Developing and using conceptual computer animation for chemistry instruction. *Journal of Chemical Education,* 75(12), 1658-1661

Burns, R. B. (1998). *Introduction to research methods*. Sydney: Longman.

Byres, W. (2001). Using questions to promote active learning in lectures. *University Chemistry Education,* 5, 24-30.

Byrne, M. D., Catrambone, R., & Stasco, J. T. (1999). Evaluating animations as students aids in learning computer algorithms. *Computers & Education,* 33, 253-278.

Byrnes, J. (1988). Formal operations: A systematic reformulation. *Developmental Review,* 8, 66-86.

Cakir, O. S., Yuruk, N., & Geban, O. (2001, April). *Effectiveness of conceptual change text oriented instruction on students' understanding of cellular respiration concepts*. Paper presented at the Annual Meeting of the National Association for Research in Science Teaching, St Louis: Missouri.

Campbell, D. T., & Stanley, J. C. (1963). *Experimental and quasi-experimental design for research.* Chicago: Rand McNally.

Campbell, R. L. (2002, April 25). *Jean Piaget's genetic epistemology: appreciation and critique*. Retrieved 8 August, 2005, from www.hubcup.clemson.edu/~campber/index.html.

Cangelosi, J. S. (1982). *Measurement and evaluation.* Dubuque: WMC Brown.

Cannon, R., & Newble, D. (2000). *A handbook for teacher in universities and colleges*. London: Kagan Page.

Caravita, S. (2001). A re-framed conceptual change theory? *Learning and Instruction*, 11, 421-429.

Caravita, S., & Hallden, O. (1994). Re-framing the problem of conceptual change. *Learning and Instruction,* 4, 89-111.

Carey, S. (1985). *Conceptual change in childhood.* Cambridge: The MIT Press.

Carey, S. (2000). Science education as conceptual change. *Journal of Applied Development Psychology,* 21(1), 13-19.

Cassata, A.E., Himangshu, S. & Iuli, R. J. (2004, October). *What Do You Know? Assessing change in student conceptual understanding in Science.* Paper presented at the Proceedings of the 1st International Conference on Concept Mapping, Pamplona, Spain.

Chan, F.-M. (2002, October). *ICT in Malaysian school: Policy and strategies.* Paper presented at the Seminar/Workshop on the Promotion of ICT Education to Narrow the Digital Divide, Tokyo.

Chan, C., Burtis, J., & Bereiter, C. (1997). Knowledge building as a mediator of conflict in conceptual change. *Cognition and Instruction, 15*, 1-40.

Chinn, C. A. & Brewer, W. F. (1998). An empirical test of a taxonomy of responses to anomalous data in science. *Journal of Research in Science Teaching*, 35(6), 623-654.

Che Lah, N., & Loke, S. H. (2004, October). *Proses kognitive pelajar dalam pembelajaran elektrokimia* [Student's cognitive process in learning electrochemistry]. Paper presented at the National Conference on Science & Mathematics Education, Kuala Lumpur, Malaysia.

Chi, M. T. H. (1992). Conceptual change within and across ontological categories: Example from learning and discovery in science. In R. Giere. *Cognitive models of science: Minnesota studies in the philosophy of science* (pp. 129-186). Minneapolis: University of Minnesota Press.

Chi, M. T. H. (2001). *Why do students fail to understand complex dynamic concept*. Seattle: American Educational Research Association.

Chi, M. T. H., & Hausmann, R.G.M. (2003). Do radical discoveries require ontological shift? *International handbook on innovation*. In L. V. Shavinina & R. Sternberg. (pp. 430-444). New York: Elsevier Science.

Chi, M. T. H., & Roscoe, R. D. (2002). The processes and challenges of conceptual change. In M. Limon & L. Mason. *Reconsidering conceptual change. Issues in theory and practice* (pp. 3-27). Netherlands: Kluwer.

Chi, M. T. H., Slotta, J. D., & deLeeuw, N. (1994). From things to processes: A theory of conceptual change for learning science concept. *Learning and Instruction,* 4, 27-43.

Chiu, M. H., Chou, C. C., & Lui, C. J. (2002). Dynamic processes of conceptual change: Analysis of constructing mental models of chemical equilibrium. *Journal of Research in Science Teaching,* 39(8), 688-712.

Chou, C.-Y. (2002). Science teachers' understanding of concepts in chemistry. *Procedure of National Science Council (Taiwan),* 12(2), 73-78.

Clark, D., & Jorde, D. (2004). Helping students revise disruptive experientially supported ideas about thermodynamics: Computer visualizations and tactile models. *Journal of Research in Science Teaching,* 41(1), 1-23.

Clark, M. P., & Wentworth, C. D. (1997, April). *Constructivism and the development of multimedia applications.* Paper presented at the Proceedings of the 30th Annual Small College Computing Symposium, University of Wisconsin-Parkside, Wisconsin.

Cohen, J. (1988). *Statistical power analysis for the behavioural sciences*. New York: Academic Press

Cohen, L., Manion, L., & Morrison, K. (2000). *Research method in education.* New York: Routledge Falmer

Cook, T. D., & Campbell, D. T. (1979). *Quasi-experimentation: Design and analysis issues for field setting*. Boston, MA: Houghton Mifflin Co.

Crowther, D. T. (1997). The constructivist zone. *Electronic Journal of Science Education,* 2(2), 1-9.

Dalgano, B. (1996, December). *Constructivist computer assisted learning: Theories and techniques.* Paper presented at The Annual Conference of the Australasian Society for Computers in Learning in Tertiary Education (ASCILITE), Adelaide, Australia.

Daud, M. Y. (2003). *Pembinaan perisian pengajaran kimia (Elektrolisis) berasaskan web* (Development of web-based chemistry instruction [Electrolysis]). Unpublished Master Dissertation. Universiti Kebangsaan Malaysia, Bangi.

Davis, J. (2001). *Conceptual change.* In M. Orey (Ed.), Emerging perspectives on learning, teaching, and technology. Retrieved Mac 25, 2003, from http://itstudio.coe.uga.edu/ebook/nceptualchange.htm.

Dethlefs, T. M. (2002). *Relationship of constructivist learning environment to student attitudes and achievement in High School Mathematics and Science.* Unpublished Doctor of Philosophy Dissertation, The University of Nebraska, Nebraska.

de Jong, T., van Joolingen, W.R., Swaak, J., Veermans, K., Limbach, R., King, S., & Gureghian, D. (1998). Self-directed learning in simulation-based discovery environments. *Journal of Computer Assisted Learning, 14*, 235-246.

Denzin, N. K. (1990). Triangulation. In J. P. Keeves (Ed.), *Educational research, methodology, and measurement: An international handbook* (pp. 511-513). Illinois: Pergamon Press.

diSessa, A. A. (2002). Why conceptual ecology is a good idea. In M. Limon & L. Mason. *Reconsidering conceptual change. Issues in theory and practice* (pp. 3-27). Netherlands: Kluwer.

Diakidoy, I-A. N., & Kendeou, P. (2001). Facilitating conceptual change in astronomy: A comparison of the effectiveness of two instructional approaches. *Learning and Instruction,* 11, 1-20.

Dimock, V., & Boethel, M. (2001, December). *Characteristic of constructivist learning environment.* Retrieved 10 April, 2003, from www.sedl.org/pubs/tec27/8.html.

DiPietro, K. (2004). The effect of a constructivist intervention on pre-service teachers. *Educational Technology & Society,* 7(1), 63-77.

Douglas, J. E. (1990). Visualization of electron clouds in atom and molecules. *Journal of Chemical Education,* 67, 42-44.

Driscoll, M. P. (2000). *Psychology of learning for instruction* (2nd ed.). Boston: Allyn and Bacon.

Driver, R., Guesne, E., & Tiberghien, A. (1989). *Children's idea in science.* Philadelphia: Open University Press

Driver, R., & Oldham, D. (1986). A constructivist approach to curriculum development in science. *Studies in Science Education,* 13, 105-122.

Duffy, T. M., & Cunningham, D. J. (1996). Constructivism: Implication for the design and delivery of instruction. In Jonassen D. H (Ed.), *Handbook of research for educational communications and technology* (pp. 170-198). New York: Simon Schuster Macmillan.

Duit, R. (1995). The constructivist view: A fashionable and fruitful paradigm for science education research and practice. In B. G. Wilson, R. H. Yeany & B. K. Britton. *The psychology of learning science* (pp. 271 - 285). Hillsdale, NJ: Lawrence Erlbaum Associates.

Duit, R. (2002, March). *Conceptual change - Still a powerful frame for improving science teaching and learning?* Paper presented at the Third European Symposium on Conceptual Change, Turku, Finland.

Duit, R., Roth, W-M., Komorek, M., & Wilbers, J. (2001). Fostering conceptual change by analogies - Between Scylla and Charybdis. *Learning and Instruction,* 11, 283-303.

Duit, R., & Treagust, D. F. (2003). Conceptual change: A powerful framework for improving science teaching and learning. *International Journal of Science Education,* 25(6), 671-688.

Dykstra, D. I., Boyle, C. F., & Monarch, I.A. (1992). Studying conceptual change in learning physics. *Science Education,* 76(6), 615-652.

de Jong, T., & van Joolingen, W.R. (1998). Scientific discovery learning with computer simulations of conceptual domains. *Review of Educational Research,* 68(2), 179-201.

Ebel, R. L. (1972). *Essential of educational measurement*. Englewood Cliff, NJ: Prentice-Hall Inc.

Edelson, D. C. (2001). Learning-for-Use: A framework for the design of technology-supported inquiry activities. *Journal of Research in Science Teaching,* 38(3), 355-385.

Edwards, H., Smith, B, & Webb, G. (2001). *Lecturing: Case studies, experience and practice*. London: Kogan.

Eggen, P., & Kauchak, D. (1997). *Educational psychology: Windows on classroom*. Columbus, Ohio: Prentice Hall.

Eilam, B., & Poyas, Y. (2002, March). *Conceptual change in teacher education.* Paper presented at The Third European Symposium on Conceptual Change, A Process Approach to Conceptual Change, Turku, Finland.

Elby, A. (2000). What students' learning Of representations tell us about constructivism. *Journal of Mathematical Behaviour,* 12, 481-502.

Epstein, H. (2003). Imaging Piaget. *The Scientist,* 17(24), 9.

Ertepinar, H., and Geban, O. (1996). Effect of instruction supplied with the investigative-oriented laboratory approach on achievement in a science course. *Educational Research*, 38, p. 333-341.

Eryilmaz, A. (2002). Effects of conceptual assignments and conceptual change discussions on students' misconceptions and achievement regarding force and motion. *Journal of Research in Science Teaching,* 39(10), 1001-1015.

Feldman, D. H., & Fowler, R.C. (1977). The nature(s) of developmental change: Piaget, Vygotsky, and the transition process. *New Ideas in Psychology,* 15(3), 195-210.

Fensham, P., & Harlen, W. (1999). School science and public understanding of Sscience. *International Journal of Science Education,* 21, 755-763.

Ferguson, G. A. (1971). *Statistical analysis in psychology and education.* New York: McGraw-Hill.

Field, A. (2000). *Discovering statistics using SPSS for Windows.* London: SAGE Publications.

Flick, U. (1998). *An Introduction to qualitative research.* London: SAGE Publications

Fong-Mae, C. (2002, October). *ICT in Malaysia schools: Policy and strategies.* Paper presented at Promotion of ICT Education to Narrow the Digital Divide, Tokyo.

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

Gance, S. (2002) "Are constructivism and computer-based learning environments incompatible?" *Journal of the Association for History and Computing*, *5*(1), 103-123

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

Garrad, J. E., West, L. T. H., & Feldman, D. H. (1985). Describing the cognitive structures of learners following instruction in chemistry. In L. T. H. West and A. L. Pines, *Cognitive structure and conceptual change*. New York: Academic Press.

Garratt, J. (1998). Inducing people to think. *University Chemistry Education,* 2(1), 29-44.

Glasersfeld, E. von. (1987). *The Construction of knowledge: Contribution to conceptual semantics*. Salinas, CA: Intersystem.

Glasersfeld, E. von. (1995). *Radical constructivism: A way of knowing and learning*. Washington: The Falmer.

Graffam, B. (2003). Constructivism and understanding. *The Journal of Secondary Gifted Education,* 15(1), 13-22.

Greenbowe, T. J. (1994). An interactive multimedia software program for exploring electrochemical cells. *Journal of Chemical Education,* 71, 555-557.

Gronlund, N. E. (1985). *Measurement and evaluation in teaching*. New York: MacMillan.

Gros, B. (2002). Knowledge construction and technology. *Journal of Educational Multimedia and Hypermedia,* 11(4), 323-334.

Hakkarainen, K. (2003). Progressive inquiry in a computer-supported biology class. *Journal of Research in Science Teaching*, 40(10), 1072-1088.

Haney, J. J., Czerniak, C. M, & Lumpe, A. T. (2003). Constructivist beliefs about the science classroom learning environment from teachers, administrators, parents, community members, and students. *School Science and Mathematics,* 103(8), 111-131.

Harrison, A. G., & Treagust, D. F. (2000). Learning about atoms, molecules and chemical bonds: A case study of multiple model use in grade-11 chemistry. *Science Education, 84*, 352-381.

Hausfather, S. J. (1996). Vygotsky and schooling: Creating a social context for learning. *Action in Teacher Education*, 18 (1-10).

Hewson, M. G. (1992, June). *Conceptual change in science teaching and teacher education*. Paper presented at the Research and Curriculum Development in Science Teaching, Madrid, Spain.

Hewson, P., & Hewson, M. (1992). The status of students' conceptions. In R. Duit, F. Goldberg & H. Niedderer (Eds.), *Research in physics learning: Theoretical issues and empirical studies* (pp. 59-73). Kiel, Germany: Institute for Science Education.

Hickey, R. (1997, December). *Evaluating students' science work - The importance of what you already know*. Paper presented at the Australian Association of Research in Education Conference, Brisbane.

Huddle, P. A., & Margaret, D. W. (2000). Using a teaching model to correct known misconceptions in electrochemistry. *Journal of Chemical Education,* 77(1), 104-110.

Hutchinson, J. S. (2000). Teaching introductory chemistry using concept development case studies: Interactive and inductive learning. *University Chemistry Education,* 4(1), 3-9.

Hynd, C. (2003). Conceptual change in response to persuasive messages. In G. M. Sinatra & P. R. Pintrich (Eds), *Intentional conceptual change* (pp. 291-315). Mahwah, N.J.: Lawrence

Isaac, S., & W. B. Michael (1983). *Handbook in Research and Evaluation.* California: EdITS.

Iwanski, G. E. (2000). *Undergraduate student attitude and acceptance of computer enhanced instruction in a college nutrition course*. Unpublished research's paper, The Graduate College, University of Wisconsin, Wisconsin.

Jenkins, E. W. (2000). Constructivism in school science education: Powerful model or the most dangerous intellectual tendency. *Science & Education,* 9, 599-610.

Jimoyiannis, A., & Komis, V. (2001). Computer simulations in physics teaching and learning: A case study on students' understanding of trajectory motion. *Computer and Education,* 36, 183-204.

Jones, M. G., & Brader-Araje, L. (2002). The Impact of Constructivism on Education: Language, Discourse, and Meaning. *American Communication Journal* 5(3), 112-118.

Johar, R., Halim, L., & Othman, K. (2004). *Methodology in Teaching Science.* Kuala Lumpur: Solid Press.

John-Steiner, V. & Mahn, H. (1996). Sociocultural approaches to learning and development: A Vygotskian framework. *Educational Psychologist*, 31, 191–206.

Johnson, D. W., Johnson, R. T., & Taylor, B. (1993). Impact of cooperative and individualistic learning on high-ability students' achievement, self-esteem, and social acceptance. *The Journal of Social Psychology*, 133, 839-44.

Kennedy, D. M., & McNaught, C. (1996, December). *Interactive multimedia: Educational desert or educational oasis?* Paper presented at The Annual Conference of Australian Society of Computers in Learning in Tertiary Education, University of South Australia.

Kidder, L. H., & Judd, C.M. (1986). *Research Methods in Social Relations*. New York: Holt, Rinehart and Winstons.

Kozma, R. B., & Russell, J. (1997). Multimedia and understanding: Expert and novice responses to different representations of chemical phenomena. *Journal of Research in Science Teaching,* 34(9), 949-968.

Kokkotas, P., & Vlacos, I. (1998). Teaching the topic of the particulate nature of matter in prospective teachers training courses. *International Journal of Science Education,* 20(3), 291-303.

Krajcik, J. S. (1994). *The psychology of learning science.* New Jersey: Lawrence Erlbaum Associates.

Lawson, A. E. (2000). *Science teaching*. Belmont: Wadsworth.

Lawson, A. E., Alkhoury, S., Russell, B., Clark, B. R., & Falconer, K. A (2000). What kinds of scientific concepts exist? Concept construction and intellectual development in college biology. *Journal of Research in Science Teaching,* 37(9), 996-1018.

Lee, G. (2003). *What do we know about students' cognitive conflict in science classroom: A theoretical model of cognitive conflict process*. Retrieved 4 October, 2003, from http://www.ed.psu.edu/CI/Journals.

Lee, G, Kwon, J., & Park, S-S. (2003). Development of an instrument for measuring cognitive conflict in secondary-level science classes. *Journal of Research in Science Teaching* 40(6), 585-603.

Lee, M. N. N. (1992). School science curriculum reforms in Malaysia: world influences and national context. *International Journal of Science Education,* 14(3), 249-263.

Lee, V. S. (2003). *Creating a blueprint for constructivist classroom.* Retrieved 5 September, 2004, from http://www.ntfl.com/html/ti/blue.

Leung, A. C. K. (2003). Contextual issues in the construction of computer-based learning programs. *Journal of Computer Assisted Learning,* 19, 501-516.

Limon, M. (2001). On the cognitive conflict as an instructional strategy for conceptual change: A critical appraisal. *Learning and Instruction,* 11, 357-380.

Lin, H-S., Yang, T.C., Chiu, H-L., & Chou, H-Y. (2002). Students' difficulties in learning electrochemistry. *Proceeding of National Science Council,* 12(3), 100-105.

Linfield, R. S., & Warwick, P. (1998). Language for science. In E. Bearne (Ed.), *The use of language across the primary curriculum.* (pp. 127-138). London: Routledge.

Lowe, R. K. (2004). Interrogation of a dynamic visualization during learning. *Learning and Instruction*, 14, 257-274.

Lux, J. R., & Davidson, B. D. (2003). Guidelines for the development of computer-based instruction modules for science and engineering. *Educational Technology & Society,* 6(4), 125-133.

MacBeth, D. (2000). On an actual apparatus for conceptual change. *Science Education,* 84, 228-264.

Marbach-Ad, G., Seal, O., & Sokolove, P.G. (2001). Students' Attitudes and Recommendations Regarding their Active Learning Introductory Biology Class: A student-led study. *Journal of College Science Teaching*, 30, 434-438.

Martin, D. J. (2003). *Elementary science methods: A constructivist approach.* Belmont, CA: Wadsworth/Thompson Learning.

Mason, L. (2001). Introducing talk and writing for conceptual change: A classroom study. *Learning and Instruction,* 11, 305-329.

Mayer, R. E., Steinhoff, K., Bower, G. & Mars, R. (1995). A generative theory of textbook design: Using annotated illustrations to foster meaningful learning of science text. *Educational Technology Research and Development*, 43, 31-44.

Mayer, R., & Moreno, R. (2003). Nine ways to reduce cognitive load in multimedia learning. *Educational Psychologist,* 38(1), 43-52.

Mayer, R.E. (2003a). The promise of multimedia learning: Using the same instructional design methods across different media. *Learning and Instruction*, 13, 125-139.

Mayer, R. E. (2003b). *Learning and instruction*. Upper Saddle River, NJ: Prentice-Hall.

Mazens, K., & Lautrey, J. (2003). Conceptual change in physics: Children's naive representations of sound. *Cognitive Psychology,* 18, 159-176.

Merriam, S. B. (1998). *Qualitative research and case study application in education: Revised and expanded from study case research in education.* CA: Jossey-Bass.

McNaught, C. (1996, December). *The nature of IT and its implications for practices and policy in High Education.* Paper presented at the Annual Conference of Australian Society of Computers in Learning in Tertiary Education, University of South Australia.

Merriam, S. B. (1988). *Case Study Research in Education.* San Francisco: Jossey-Bass.

Michael, K. Y. (2001). The Effect of a computer simulation activity versus a hands-on activity on product creativity in technology education. *Journal of Technology Education,* 13(3), 31-43.

Michas, A., & Berry, B. (2000). Learning a procedural task: Effectiveness of multimedia presentations. *Applied Cognitive Psychology*, 14, 555-575

Michelle, D. P., Carter, G, & Wiebe, E. N. (2005). Visual representation of DNA replication: Middle grades students' perception and interpretations. *Journal of Science Education and Technology*, 14(3), 353-471.

Miller, A.H., Imrie, B.W., & Cox, K. (1998). *Student assessment in high education. Handbook for assessing performance.* London: Kogan Page.

Milrad, M. (2002). Using construction kits, modeling tools and system dynamics simulations to support collaborative discovery learning. *Educational Technology & Society,* 5(4), 1-18.

Ministry of Education Malaysia (1994a). *PuLSaR Modul 2: Kemahiran Saintifik* [PuLSaR Module 2: Scientific Skills]. Kuala Lumpur: Curriculum Development Centre.

Ministry of Education Malaysia (1994b). *PuLSaR Modul 3: Kemahiran Berfikir* [PuLSaR Module 3: Thinking Skills]. Kuala Lumpur: Curriculum Development Centre.

Ministry of Education Malaysia. (1996). *PuLSaR Modul 11: Pengoperasian Kemahiran Proses Sains dalam Pengajaran dan Pembelajaran* [PuLSaR Module 11: The Operation of Science Process Skills in Teaching and Learning]. Kuala Lumpur: Curriculum Development Centre.

Ministry of Education (1997). *Kajian Keefisienan Penggunaan dan Pengurusan Makmal Sains di Sekolah Menengah* [Study on the Efficiency and Science Laboratory Management in Secondary School]. Kuala Lumpur: Division of Planning and Research for Educational Practice.

Ministry of Education Malaysia (1999). *Current trends and issues in training practices for educators in the areas of ICT.* A reports for APEC Project - Integration of Information and Communication Technologies (ICTs) through Teacher Professional Development and Pre-Service Training. Kuala Lumpur.

Ministry of Education (2001a). *Education in Malaysia: A journey to excellence.* Kuala Lumpur: AG Grafik.

Ministry of Education Malaysia (2001b). *Pembelajaran Secara Konstructivisme* [Learning as Constructivism]. Kuala Lumpur: Curriculum Development Centre.

Ministry of Education (2002). *Integrated curriculum for secondary school. curriculum specifications (Science Form 1).* Kuala Lumpur: Curriculum Development Centre.

Ministry of Education (2003). *Laporan Prestasi SPM 2002.* [Report on SPM Performance 2002]. Kuala Lumpur: Lembaga Peperiksaan Malaysia

Ministry of Education (2004a). *Laporan Prestasi SPM 2003.* [Report on SPM Performance 2003]. Kuala Lumpur: Examination Syndicate.

Ministry of Education (2004b). *Integrated curriculum for secondary school. curriculum specifications (Chemistry Form Four).* Kuala Lumpur: Curriculum Development Centre.

Moallem, M. (2001). Applying constructivist and objective learning theories in the design of a web-based course: Implications for practice. *Educational Technology & Society,* 4(3), 113-125.

Neo, M., & Neo, K. (2002). Building a constructivist learning environment using a multimedia design project - A Malaysia experience. *Journal of Educational Multimedia and Hypermedia,* 11, 141-154.

Newton, P., Driver, P., & Osborn, J. (1999). The place of argumentation in the pedagogy of school science. *International Journal of Science Education,* 21(5), 553-576.

Niaz, M. (1995). Cognitive conflict as a teaching strategy in solving chemistry problem: A dialectic-constructivist perspective. *Journal of Research in Science Teaching,* 32, 959-970.

Niaz, M., Aguilera, D., Maza, A., & Liendo, G. (2000). Arguments, contradictions, resistances, and conceptual change in students' understanding of atomic structure. *Science Education,* 86, 505-525.

Nieswandt, M. (2001). Problems and possibilities for learning in an introductory chemistry course from a conceptual change perspective. *Science Education,* 85, 158-179

Novak, J. D. (2002). Meaningful learning: The essential factor for conceptual in limited of inappropriate prepositional hierarchies leading to empowerment of learners. *Science Education,* 86, 548-571.

Novak, J. D., Mintzes, J. J., & Wandersee, J. H. (2000). Learning, teaching, and assessment: A human constructivist perspectives. In J. D. Novak, J. J. Mintzes & J. H. Wandersee (Eds.), *Assessing science understanding: A human constructivist view* (pp. 1-13). New York: Academic Press.

Nussbaum, E. M., & Sinatra, M. G. (2003). Argument and conceptual engagement. *Contemporary Educational Psychology,* 28(3), 384-395

Nussbaum, J. (1985). The particulate nature of matter in the gaseous state. In R. Driver, E. Guesne, A. Tiberghien. *Children's ideas in science* (pp. 56-68). Philadelphia: Open University.

Odubunmi, O. & Balogun, T.A., (1991). The effect of laboratory and lecture teaching methods on cognitive achievement in integrated science. *Journal of Research in Science Teaching*, 28(3), 213-223.

Ogunsola, B., Merfy, F., & Comfort, O. (1998, April). *The Effect of a conceptual change teaching strategy on attitude towards the learning of some biology concepts.* Paper presented at The Annual Meeting of the National Association for Research in Science Teaching, San Diego.

Osborne, R. J., & Freyberg, P. (1985). *Learning in science: The implication of children's science*. London: Heinemann Educational Books.

Osborne, R. J., & Gilbert, J. K. (1980). A technique for exploring student's view of the world. *Physics Education,* 15, 361-362.

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

Pallant, J. (2001). *SPSS survival manual.* Victoria: Allen & Unwin.

Partington, J. (1994). Double-marking students' work. *Assessment and Evaluation in High Education,* 19, 57-60.

Patton, M. Q. (1990). *Qualitative evaluation and research methods.* Newbury Park, CA: SAGE.

Paivio, A. A. (1979). *Psychological processes in comprehension of metaphor.* London: Cambridge University Press.

Piaget, J. (1977). *The development of thought: Equilibration of cognitive structures.* New York: Viking.

Pines, A.L., Novak, J. D., Posner, G. D., & Vankirk, J. (1978). Clinical interview: A method of evaluating cognitive structure (Research Report No. 6, Curriculum Series). New York: Cornell University.

Posner, G. J., & Gertzog, W. A. (1982). Clinical interview and the measurement of conceptual change. *Science Education,* 66(2), 195-209.

Posner, G. J., & Strike, K. A. (1985). A conceptual change view of learning and understanding. In L. T. H. West and A. L. Pines. *Cognitive structure and conceptual change* (pp. 221-230). New York: Academic Press.

Posner, G. J., Strike, K.A., Hewson, P. W., & Gertzog, W.A. (1982). Accommodation of a scientific conception: Towards a theory of conceptual change. *Science Education,* 66, 211-227.

Reid, D.J., Zhang, J., & Chen, Q (2003). Supporting scientific discovery learning in a simulation environment. *Journal of Computer Assisted Learning,* 19, 9-20.

Ronen, M., & Eliahu, M. (2000). Simulation - A bridge between theory and reality: The case of electric circuit. *Journal of Computer Assisted Learning,* 16, 14-26.

Russell, J. W., Kozma, R.B., Jones, T., Wykoff, J. & Marx, N. (1997). Use of simultaneous-synchronized macroscopic, microscopic, and symbolic representations to enhance the teaching of chemical concepts. *Journal of Chemical Education,* 74, 23-29.

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

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

Sanger, M. J., & Greenbowe, T. J. (1999). An analysis of college chemistry textbooks as sources of misconception and errors in electrochemistry. *Journal of Chemical Education,* 76(6), 853-860.

Sanger, M. J., & Greenbowe, T. J. (2000). Addressing students' misconceptions concerning electron flow in aqueous solutions with instruction including computer animations and conceptual change strategies. *International Journal of Science Education, 22*, 521-537.

Sanger, M. J., Phelps, A.J., & Fienhold, J. (2000). Using a computer animation to improve students' conceptual understanding of a can-crushing demonstration. *Journal of Chemical Education,* 77(11), 1517-1520.

Scaife, M. and Rogers, Y. (1996) External cognition: How do graphical representations work? *International Journal of Human-Computer Studies,* 45, 185-213

Scruggs, T. E., & Mastropieri, M. A. (1992). Classroom applications of mnemonic instruction: Acquisition, maintenance, and generalization. *Exceptional Children*, 58, 219-229.

Shavelson, R. J. (1988). *Statistics for the behavioral sciences.* Massachusetts: Allyn and Bacon.

Silverman, D. (1993). *Interpreting qualitative data.* London: SAGE.

Smithson, M. (2000). *Statistics with confidence*. London: SAGE.

Strike, K. A., & Posner, G. J. (1985). A conceptual change view of learning and understanding. In L. T. H. West and A. L. Pines. *Cognitive Structure and Conceptual Change* (pp. 221-230). New York: Academic Press Inc.

Strike, K. A., & Posner, G. J. (1992). A revisionist theory of conceptual change. In R. Duschl & R. Hamilton (Eds.), *Philosophy of science, cognitive psychology, and educational theory and practice* (pp. 147-176). Albany: SUNY.

Sung, W. T., & Ou, S. C. (2002). Learning computer graphics using virtual reality technologies based on constructivism - Case study of the WebDeGrator system. *Interactive Learning Environments,* 10(3), 177-197.

Sutton, C. R. (1980). The learner's prior knowledge: A critical review of techniques for probing its organization. *European Journal of Science Education,* 2(2), 107-120.

Susskind, J. E. (2005). PowerPoint's power in the classroom: Enhancing students' self-efficacy and attitudes. *Computer & Education*, 45, 203-215.

Swaak, J., & de Jong, T. (2001). Discovery simulations and the assessment of intuitive knowledge. *Journal of Computer Assisted Learning,* 17, 284-294.

Taber, K. S. (2000). Chemistry lectures for universities?: A review of constructivist ideas. *University Chemistry Education,* 2(2), 63-71.

Tao, P. K., & Gunstone, R. F. (1999). The process of conceptual change in force and motion during computer-supported physics instruction. *Journal of Research in Science Teaching,* 36(7), 859-882.

Tuan, H-L, Chin C-C and Chen, S-F, (2005). Investigating the effectiveness of inquiry instruction on the motivation of different learning styles students. *International Journal of Science and Mathematics Education,* 3, 541-566.

Tsai, C. C., & C. Chou (2002). Diagnosing students' alternative conceptions in science. *Journal of Computer Assisted Learning,* 18, 157-16.

Tsaparlis, G & Angelopoulos, V. (2000). A model of problem-solving: Its operation, validity, and usefulness in the case of organic-synthesis problems. *Science Education*, 84, 151-153

Tytler, R. (2002). Teaching for understanding in science. *Australian Science Teachers' Journal,* 48(4), 30-35.

UNESCO (2003). Development of Education: National Report Malaysia, International Bureau of Education: UNESCO.

Vosniadou, S., & Brewer, W. F. (1992). Mental models of the earth: A study of conceptual change in childhood. *Cognitive Psychology,* 24, 535-585.

Vosniadou, S., Ioannides, C., Dimitrakopoulou, C., & Papademetriuo, E. (2001). Designing learning environments to promote conceptual change in science. *Learning and Instruction,* 11, 381-419.

Vygotsky, L. (1978). *Mind in society: The development of high psychological process*. Cambridge, MA: Harvard University.

Vygotsky, L. (1989). *Thought and language* (4th ed.). Massachusetts: The MIT.

Wang, J-R. (2004). Enhancing elementary science teachers' knowledge of teaching: The case of designing and implementing an instructional unit. *International Journal of Science and Mathematics Education,* 2, 455-476.

Weasenforth, D., Biensenbach-Lucas, S. & and Meloni, C. (2002). Realizing constructivist objectives through collaborative technologies: Threaded discussions. *Language Learning and Teaching,* 6(3); 58-86

West, L. T. H., & Pines, A. L. (1985). *Cognitive structure and conceptual change*. New York: Academic Press.

Wiersma, W. (1995). *Research methods in education*. Boston: Allyn and Bacon.

Windschitl, M., & Andre, T. (1998). Using computer simulation to enhance conceptual change: The roles of constructivist instruction and students epistemological beliefs. *Journal of Research in Science Teaching,* 35, 145-160.

Zin, S. M. S., & Lewin, K.M. (1993). Insight Into Science Education: Planning and Policy Priorities in Malaysia. Paris, UNESCO.