International Education Journal, ERC2004 Special Issue, 2005, 5(5), 29-42.
ISSN 1443-1475 © 2005 *Shannon Research Press*.
http://iej.cjb.net

Computer-animated instruction and students' conceptual change in electrochemistry: Preliminary qualitative analysis

Othman Talib
University of Adelaide, Graduate School of Education *othman.talib@student.adelaide.edu.au*

Robert Matthews
University of Adelaide, Graduate School of Education *robert.matthews@.adelaide.edu.au*

Margaret Secombe
University of Adelaide, Graduate School of Education *margaret.secombe@adelaide.edu.au*

This paper discusses the potential of applying computer-animated instruction (CAnI) as an effective conceptual change strategy in teaching electrochemistry in comparison to conventional lecture-based instruction (CLI). The core assumption in this study is that conceptual change in learners is an active, constructive process that is enhanced by the pedagogic use of computer-animated images. The combination of pretest-posttest written answers and interview transcripts were used to analysis interviewees' conceptual change progression. The preliminary results of this study support the conceptual change model as proposed by Posner, Strike, Hewson and Gertzog (1982) and Strike and Posner (1992).

Computer-animated instruction, conventional lecture-based instruction, constructivist, conceptual change, electrochemistry

INTRODUCTION

Computer-mediated instruction compared to conventional lecture-based instruction has not been widely implemented in higher education. In fact, conventional lecturing remains the main teaching method in delivering knowledge to students. A typical conventional lecture uses overhead projectors and prepared transparencies with charts, graphs or static illustrations. Most of the time, the conventional lecture is conducted through one-way communication, ignoring class discussion and other student involvement. Students are passive listeners, taking notes from transparencies and from the lecturer's explanations. The explaining of complex conceptions through static illustrations on overhead transparencies is time consuming. This is made more difficult if the conception is not only complex, but also abstract and dynamic. Practically, it is also hard to update the content of the transparencies, thus, limiting the reusability of the transparencies.

Numerous computer software products are available to substitute the practice of using transparencies. One of the more advanced software applications is computer animation. This dynamic application is potentially useful to stimulate students' engagement in fulfilling their learning objectives (Neo, 2002). Such stimulation is essential to generate a constructivist teaching and learning environment. It is argued that embedding animations to create a constructivist environment in tertiary education will enhance students' conceptual change. As stated by Maier, Barnett, Warren and Brunner (1998, p.69), the advantages of using computer animation in teaching at higher education institutions rely on its ability "to stimulate real-life processes….create, elaborate, develop and explore graphical representations interactively".

The intensive researches in constructivist approaches and computer-mediated instruction have recently led to the use of computers as an innovation in teaching and learning science. Researchers claim that computer-mediated instruction in comparison to the conventional methods of teaching can enhance the discovery environment (Reid, Zhang and Chen., 2003), transform learners' alternative conceptions (Jimoyiannis and Komis, 2001), support a collaborative learning environment (Milrad, 2002), create technological processes (Micheal, 2001), enhance understanding of scientific conceptions (Ronen and Eliahu, 2000), provide an interactive 3-D visual stimuli environment (Sung and Ou, 2002); stimulate students' scientific problem solving skills (River and Vockell, 1987), and enhance students conceptual change (Toa and Gunstone, 1999).

This study used Flash MX as the authoring computer software program to create animations as teaching materials. These materials conceptualise and portray scientific phenomena in a dynamic and constructivist way. Animation for the purpose of this study is defined by Byrne, Catrambone and Stasco (1999) as a process of moving and changing any object on the computer screen to replicate a simulation of a theoretical dynamic, abstract and evolving process, event or phenomena. According to McNaught (1996), animation presentation is aligned with the constructivist view especially when it is designed to provide real situations or processes in step-by-step sequences. Moreover, integrating contents and processes together increases the students' experience with the authentic environment as well as in-depth content understanding (Edelson, 2001). This is quite distinct from the use of computers as reinforcement tools using ready-made courseware, which learners work by themselves.

CONCEPTUAL CHANGE MODEL

In 1982, Posner, Strike, Hewson and Gertzog proposed their conceptual change model (CCM), which became one the most influential and guiding theories to understand conceptual change in science pedagogical research. This founding article stressed that constructing new knowledge is related to the modification of students' existing conceptions. In explaining the conceptual change from a constructivist epistemology, the authors redefined the term assimilation (generally described as weak conceptual change) to be "the use of existing concepts to deal with new phenomena" whist the term accommodation (generally describes as strong conceptual change) to be "if the student's existing concepts are inadequate to grasp some new phenomena successfully….then the student must replace or organise his central concepts (own conceptions)" (Posner, Strike, Hewson and Gertzog, 1982, p.212). Thus assimilation involves the addition of new knowledge without the involvement, changing, linking or interaction of existing conception. This simple addition of information can be considered as rote learning if the information is purely memorised without understanding. The accommodation involves the revision of conceptions, which leads to a revisionist theory of conceptual change by Strike and Posner (1992). They stressed accommodation more than assimilation because accommodation is hard to achieve and is a process of cognitive development.

Strike and Posner (1992) highlighted four conditions of teaching and learning processes, which must first be fulfilled before accommodation takes place in a student's mind. In the same article, they described briefly factors of conceptual ecology, which may influence the student's conceptual change process. The conditions are as follow:

a) the learner must be dissatisfied with his or her current conception;

b) the alternative conception must be intelligible;

c) the alternative conception must be plausible; and

d) the alternative conception must be fruitful.

Another concept in the CCM is called conceptual ecology, which may influence the student's conceptual change process. The most important features of a learner's conceptual ecology, as adapted from Posner, Strike, Hewson and Gertzog (1982, p.215), are anomalies which arise from the learner's existing knowledge; analogies and metaphors, which facilitate the meaning and intelligibility of new ideas; epistemological commitments which include successful explanation in some interviewee matter; and metaphysical beliefs about science and science concepts. Epistemological commitments and metaphysical beliefs then become part of a learner's rationality to accept or to reject new ideas.

From the ontological perspective as proposed by Chi, Slotta and deLeeuw (1994) and Chi and Roscoe (2000), conceptual change is considered easy when the initial conception and the new conception belong to the same category or are ontologically compatible. For example, "atom releases electrons" (initial conception) can be easily exchanged to "cation releases electrons" (new conception). If the initial conception and new conception are ontologically different, conceptual change is a bit harder. It needs radical conceptual change. For example, the understanding that "cathode is an electrode" (initial concrete conception) and "cathode is where the process of reduction occurs" (abstract scientific conception) needs rearrangement of the ontology category.

Specifically in chemistry education, Greenbowe (1994) has suggested in his article the need for computer-mediated instruction, especially computer animation. He mentioned that most conventional chemistry lectures emphasise the symbolic representation (such as balancing equations) and macroscopic representation (such as changes in state), but leave the microscopic representation unexplored. He specifically stated that "as a result, students have difficulty thinking about chemical processes at the molecular level". Therefore, he suggested that the computer animations could be used as an effective tool in presenting chemical processes at the microscopic level as well as symbolic and macroscopic level, and so to enhance students' conceptual change.

There are indeed critics about the practicality of the conceptual change model in science education. Even though CCM is "the best known conceptual change model in science education" (Duit and Treagust, 2003, p.673), it does possess certain limitations. In one of their latest articles, the authors listed limits of the CCM approach in application to science education. First, CCM only focuses on isolated conceptions of science rather than the changes of overall views of the underlying concepts of the nature of science. Secondly, CCM approaches do not take into consideration affective aspects of learning such as students' perception towards science learning. As supported by Lee, Kwon and Park (2003, p.587) "sometimes, affective reasons are more important than logical/cognitive reason in students' learning".

METHOD

Sampling

Eighty-five first-semester science matriculation students at the Matriculation Centre, International Islamic University, Malaysia were randomly chosen from the total research population of 250 and were randomly assigned to form a CAnI group (n=45) and a CLI group (n=40). Six subjects were selected for interview from the CAnI group (n=3) and the CLI group (n=3) on the basis that they obtained the highest gained score between pretest and posttest. The subjects in the CLI group were coded as A1, A2 and A3 and the subjects in the CAnI group were coded as B1, B2 and B3. This purposeful sampling, also known as judgmental sampling (Berg, 2001) was used to select a specific sample of participants with certain criteria. The criterion was based on the hypothesis that the higher the increase in score obtained by the participants, the more conceptual change progress had occurred. They can be considered as a reference group or key informant and provide valuable information in understanding the process of conceptual change.

Procedure

First, the pretest was administered to the CLI and CAnI groups. The pretest and posttest instruments were designed to evaluate students' understanding of the targeted electrochemical conceptions. The pretest took 40 minutes to complete. This was followed by four unit lectures on electrochemistry as treatments. Each unit was designed as a normal 50-minute lecture. The instructor for the CLI group used conventional methods, using prepared transparencies and whiteboard. Instruction was primarily based on the lecturer's direct verbal explanation and presentation using prepared transparencies. Meanwhile, lectures in the CAnI group used computer-animated instruction, employing a lap-top computer and data projector. Their lesson focused on explaining the step-by-step process of electrochemistry through computer-animated presentation. For each step, students were engaged with class discussion and animation sequences. At the completion of sessions, a 40-minute posttest was administered to both groups. Finally, six students who obtained the highest gain scores (three students from each group) were selected. These students were interviewed for 30 to 40 minutes.

Interview Techniques

The purpose of the interview was to explore the interviewees' ideas or thinking processes behind their pretest and posttest written answers and to obtain in-depth explanation in order to track their conceptual change progress in electrochemical conceptions.

This study used a focused interview, which adapts clinical interviews, interviews-about-instances (IAI) and interviews-about-events (IAE). The combination of semi-structured and unstructured questions in clinical interviews, IAI and IAE, gave a more flexible design, with the main function being to "focus attention on a given experience and its effects" to the interviewee (Kidder and Judd, 1986, p.274). These types of interview give more scope for the interviewer to focus and direct the flow of the interview onto the specific knowledge content of electrochemistry. Moreover, clinical interviews, IAI and IAE have common characteristics in terms of probing learners' understanding. In this study, the questions were focused on the interviewee's written answers in pretest and posttest, with follow-up questions asked to obtain in-depth specific information and to probe the interviewee's understanding, reasoning and strategies used in answering pretest and posttest questions.

Each interview took approximately 30 to 40 minutes. The interviews were conducted on a one-to-one basis. The interview was audio-taped and then transcribed by the interviewer as soon as possible as suggested by Osborne and Freyberg (1985) for the interviewer to improve the technique of asking questions for the next interview. During each interview, the interviewees were asked to verbalise their answer and to illustrate their explanations of diagrams or chemical equations. This may provide extra information about their current understanding or existing knowledge. Finally, by combining interviewee's responses with written answers in pretest and posttest it was hoped to provide an insight into the interviewee's conceptual change progression.

ANALYSIS OF QUALITATIVE DATA

The combination of pretest-posttest written answers and interview transcripts, were used to analyse interviewees' conceptual change progression. The analysis of five pretest-posttest questions are given in the following section.

Question 1:

Define each of the following:
a. Oxidation (pretest) / Reduction (posttest)
b. Cathode (pretest) / Anode (posttest)

CLI Group: A1, A2, A3

In the pretest, only A3 was able to write the correct answer. The response shows only A3 remembered the factual knowledge about oxidation and so was a part of her existing knowledge about electrochemistry. Meanwhile, A1 and A2 have some idea about oxidation; but they showed confusion between the definitions of oxidation and reduction, a basic foundation to understanding electrochemistry conceptions. A1 defined oxidation as "no. [number] of oxidation decrease" while A2 defined oxidation as "gain electron". Both definitions are actually correct for reduction.

For the second question, all subjects seemed unable to give a correct definition of cathode. A1 and A2 tried to associate cathode with "something negative". For example, A1 defined cathode as "an electrode, which attract electron" and A2 defined it as a "negative pole". A1's and A2's responses to the definition of cathode indicate typical examples of incorrect existing knowledge or misconception, which seems to be a common phenomena among students. To justify her answer, A2 said that "anode is positive", perhaps she was unsure of her own answer.

In the posttest, the definition of reduction was asked instead of oxidation. A1, A2 and A3 had no difficulty in giving the correct answer. All of them defined reduction as a process of gaining electron(s). This suggests that conventional instruction was able to change the subjects' definitions about oxidation and reduction.

For the second question, A1 and A2 again answered correctly. A1, for example, wrote that the anode "is the electrode where the oxidation occurs". Both students rationally accepted the new definition of oxidation-reduction and anode-cathode. A3, who had no idea in the pretest about a cathode, responded to the posttest question incorrectly about the anode as "the positive electrode that attracts negative ions". She was not aware of her misconception. Her reply established her strong misconception that the cathode is negative. This belief is then obviously repeated in the posttest when she answered that the anode is positive.

CAnI Group: B1, B2 and B3

In the pretest, only B3 gave the correct answer for the oxidation definition. She answered oxidation is "release the electrons to increase the oxidation number". We note that B3 seemed to remember such a definition without any reasonable understanding. B2 defined oxidation as a "process of gain[ing] electrons", while B1 had no idea about oxidation at all. These answers provide evidence that some students memorised the relationship between oxidation-reduction with the process of releasing-gaining electrons. That is why some of them were lucky to give the correct combination (oxidation-releasing electrons or reduction-gaining electrons) but some were not. In B3's case, she just remembered the combination oxidation-releasing electrons without any explanation to justify her answer.

For the second pretest question, B1, B2 and B3 failed to give the correct answer for the definition of cathode. B1, B2 and B3 defined a cathode as "receive the anion", "the negative terminal" and "receive anion" respectively. Such responses suggest that B1, B2 and B3 held misconceptions as they tried to associate cathode with 'something' negative (terminal or ions) even though it is obvious that statements such as "cathode attracts anion" contradicts with scientific common sense – anions (negative ions) move away from negatively charged electrode.

In the posttest, B1, B2 and B3 gave the correct definition of reduction. B1 and B3 defined reduction as a process of gaining electrons. For B2, reduction is a "process of accept[ing] electron in chemical reaction". This revealed that after instruction, all of them were able to grasp the definition of reduction. For the second question, B1, B2 and B3 were able to give a correct definition for anode. For B1 and B3, the anode is a terminal at which oxidation occurs while for B2, the anode is a terminal at which electrons are released.

Question 2:

> Choose the reducing agent and oxidising agent in the following reaction:
>
> $$\mathrm{Zn} + \mathrm{Cu}^{2+} \longrightarrow \mathrm{Zn}^{2+} + \mathrm{Cu}$$
>
> (i) Reducing agent is ______ (ii) Oxidising agent is ______

Question 2 was constructed to probe the extension of the subject's understanding about oxidation and reduction processes or reactions and can be easily tracked using three possible sequences of conceptual sets as follows:

Zn (reactant): Lost electrons $\longleftrightarrow$ Oxidation $\longleftrightarrow$ Reducing agent

Cu^{2+}(reactant): Gained electrons $\longleftrightarrow$ Reduction $\longleftrightarrow$ Oxidising agent

CLI Group: A1, A2 and A3

In the pretest, A1 gave correct answers in determining the reducing agent and oxidising agent, Zn and Cu^{2+} respectively. A2 and A3 however, chose Zn and Cu as the answers. Surprisingly, they gave the same answers in the posttest.

A1's responses:

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

A1: *Zinc releases electrons to form zinc ion, zinc reducing agent*

Researcher: *So, an oxidising agent?*

A1: *Gaining electrons…. so copper ion is oxidising agent*

A2's responses:

Researcher: *Rewrite the equation.*

A2: $\mathrm{Zn} + \mathrm{Cu}^{2+} \longrightarrow \mathrm{Zn}^{2+} + \mathrm{Cu}$ [Equation 1]

ox process

red process

Researcher: *Which is a reducing agent?*

A2: *Reducing agent...reduction...it reduced others…<u>Zn</u> is a reducing agent* (referring to Equation 1).

Researcher: *What about oxidising agent?*

A2: *It oxidised others………definitely copper*
Zn is a reducing agent so Cu $^{2+}$ *is an oxidising agent*

Researcher: *But your answer is Cu?*

A2: *I didn't realise that ion could be a reducing agent*

Meanwhile A3 explicitly expressed her answer:

Researcher: *Which one is a reducing agent?*

A3: $\overset{\text{reducing agent}}{\mathrm{Zn}} + \mathrm{Cu}^{2+} \longrightarrow \mathrm{Zn}^{2+} + \mathrm{Cu}$ [Equation 2]

A3: *Zinc* [referring to Equation 2]

Researcher: *How did you know?*

A3: *First I determine which one has been reduced…copper [Cu]*

Researcher: *Can you explain?*

A3: *Because the oxidation number is decreased……*

Researcher: *Please explain.*

A3: *Definitely the process of reduction….*

A1 used the concept of releasing and gaining electrons to determine the reducing agent and oxidising agent. In this case, A1 confidently associated releasing electrons (oxidation) with reducing agent and gaining electrons (reduction) with the oxidising agent. A2 gave Zn as the reducing agent because "it reduced others", and then made a conclusion that Cu is the oxidising agent. Without understanding the role of electrons, A2 failed to realise that Cu^{2+} was the one that reduced (decreasing oxidation number) not Cu. On the other hand, A3 used the oxidation number to determine which species had been reduced, then made a conclusion that Zn was a reducing agent. The way A2 and A3 explained their answers suggests their incomplete mental model and weak conceptual change regarding the concept of reducing and oxidising agents.

CAnI Group: B1, B2, B3

In the pretest, B1 and B3 wrote Zn and Cu as reducing agent and oxidising agent respectively. B2 however chose Cu^{2+} and Zn as her answers, which were definitely wrong. In the posttest, B1, B3 and B2 correctly chose Zn as reducing agent and Cu^{2+} as oxidation agent. In describing the answer, B1 for example made the following responses:

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

B1: *Reducing agent…..undergoes the oxidation process*

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

B1: *The reactant which releases electrons…*

Researcher: *Write down the equation*

B1: $Zn \rightarrow Zn^{2+} + 2e^-$ [Equation 3]

Researcher: *The other one.*

B1: $Cu^{2+} + 2e^- \rightarrow Cu$ [Equation 4]

Researcher: *Please circle the oxidising agent and reducing agent*

B1: *Definitely zinc* [Zn]

Researcher: *Which one undergoes reduction reaction?*

B1: *Copper ion*

B2's responses:

Researcher: *Which one is a reducing agent?*

B2: *First, I noticed …. Cu* $^{2+}$ *to Cu….reduction*

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

B2: *Because…it receives electrons….*

Researcher: *Please explain further.*

B2: *It* [Cu^{2+}] *receives electron…*

Researcher: *From which source?*

B2: *Zinc metal……so reduction agent is zinc*

Researcher: *What about zinc?*

B2: *Zinc...oxidation process...copper...reduction agent.*

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

B2: *Cu^{2+}*

Researcher: *Why?*

B2: *The reduction of oxidation number…*

Researcher: *Please explain.*

B2: *Reduction process…so it's oxidation agent…*

B3's responses:

Researcher: *Which one is reduction agent?*

B3: *Zinc*

Researcher: *How do you know?*

B3: *From oxidation process*

Researcher: *Please explain.*

B3: *The oxidation number increase.*

Researcher: *Oxidising agent?*

B3: *Copper*

Researcher: *Copper ion or copper atom?*

B3: *Copper ion…*

B1, B2 and B3 explained their answers based on the process of oxidation and reduction. B1 then divided the redox equation into two half equations (Equation 1 and Equation 3). This excerpt illustrates in-depth understanding and a complete mental model possessed by B1. The way B1 explaining the answers suggests the strong conceptual change regarding the concept of reducing and oxidising agents. Meanwhile B2 and B3 also used oxidation number to describe their answers. Oxidation number is actually not explained in the lecture but may be retrieved from their existing knowledge.

Question 3

What makes the molten $PbBr_2$ conduct electrical current?
Describe you answer (pretest)

What makes aqueous solution $CuSO_4$ conduct electrical current?
Describe you answer (posttest)

For this question, subjects should know the definition of electrolyte and the properties of ionic compounds ($PbBr_2$ and $CuSO_4$) in solution or molten state. Electrolytes such as $PbBr_2$ when in molten state or $CuSO_4$ when dissolved in water, produces free anions and cations. Anions (negative ions) release electrons to cations (positive ions) through the process of oxidation and reduction respectively. Electric current is carried through molten $PbBr_2$ and aqueous solution of $CuSO_4$ by the movement of ions, demonstrate the electrical conductivity of these electrolytes.

CLI Group: A1, A2 and A3

In the pretest, only A1 and A2 tried to answer the questions. For A1, molten $PbBr_2$ conducts electrical current because "in the molten $PbBr_2$, electrons move freely". When asked further, A1 explained:

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

A1: *Bromin is negative….*

Researcher: *Where is the source of electron?*

A1: *From plumbum…it releases electrons to bromin*

The answer given by A1 indicated that she associated electron with cation. However, she then clarified that plumbum is the source of electrons.

Meanwhile, A2 gave her response as "…the electron[s] can move to transfer the electrical current". In each of these answers, A1 and A2 tried to construct a logical meaning of conductivity phenomena based simply on the existence of free electrons, instead of free anions and cations.

In the posttest, A1 wrote that aqueous solution of $CuSO_4$ conducts electrical current because "there are lots of free ions". This was the answer given in the pretest. The way she repeated the answer, confirm the surface understanding possessed by A1. A2 wrote that "$CuSO_4$ have free cations and anions that can transfer the electrical current". For A3, aqueous solution of $CuSO_4$ conducts electrical current "because of the anions and cations free to move". These answers show that the way A2 and A3 had learnt was dominated by what they had already known about aqueous solutions. They realised an aqueous solution consists of free cations and anions, but not how these ionic particles produce free electrons. If A2 believed that electrons flow through the electrolyte without mentioning the redox reaction, they will not be able to understand the whole process completely.

There is a similarity in the subjects' answers. They all used the word 'free' to explain the flow of electrical current. A1 used free ions to justify her answer while A2 and A3 used free cations and anions. However, none of them described in what way that free electrons or free ions could explain the electrical conductivity of the electrolytes. If they knew that free electrons or free ions can cause electrical conductivity but did not know the conception (in this case the redox reaction) underlying this process, they have experienced weak conceptual change rather than strong conceptual change. Despite the incompleteness, all of them seem satisfied with the logic of their answers.

CAnI Group: B1, B2, B3

In the pretest, B2 and B3 mentioned the existence of cations and anions as being responsible for the electrical conductivity for molten $PbBr_2$, but failed to describe any further. B2 however, used the wrong terminologies - 'positive atom' and 'negative atom' for cation and anion respectively. In fact, there are no positive or negative atoms, because atoms are neutral. This indicates that B2 held some kind of misconception regarding the properties of atoms.

In the posttest, B1 described $CuSO_4$ as an ionic compound, which undergoes "oxidation and reduction to produce electrons". B3 knew that $CuSO_4$ contains free ions and wrote "the discharge of the ions produce the electrical current". Meanwhile B2 in the posttest wrote "anion will release electron and cation will gain electron". B1 and B2 noticed the role of anion and cation in the redox reaction in order to produce electrons. These responses show that all subjects in the CAnI group are able to provide an explanation of the phenomena, which is consistent with the conceptions as held by scientific views. The analysis indicates that the subjects in the CAnI group experienced a strong conceptual change process. It suggests the conceptions seem intelligible and plausible to the students.

Question 4:

> Explain why the cathode in an electrolytic cell of molten KCl is negatively charged whilst the cathode in Zn-Cu (Galvanic) cell is positively charged?

To answer this question, students should know that in the electrolytic or Galvanic cells, the anode is the electrode at which oxidation occurs and the cathode is where reduction occurs. However, in Galvanic cells, the anode is negative and the cathode is positive, while in electrolytic cells, the anode is positive and the cathode is negative. These differences are shown in Table 1.

Table 1. Anode and Cathode

Electrode	Process	Electrolytic Cell (molten $MgCl_2$)	Galvanic Cell (Zn-Cu)
Anode	Oxidation	Positive electrode Equation: $2Cl^- \rightarrow Cl_2 + 2e$	Negative electrode Equation: $Zn \rightarrow Zn^{2+} + 2e$ (zink is preferable of releasing electrons)
Cathode	Reduction	Negative electrode Equation: $Mg^{2+} + 2e \rightarrow Mg$	Positive electrode Equation: $Cu^{2+} + 2e \rightarrow Cu$

CLI Group: A1, A2 and A3

In the pretest, A1, A2 and A3 did not write any answer to the question. Probably they did not have any ideas from which to analyse the conceptions required for this question. In the posttest, A1, who gave a correct definition of anode in Question 1b, gave a partially correct answer to Question 4. She wrote that the cathode in the electrolytic cell is negatively charged "because it receive ē [electrons] from the battery whereas cathode in the Galvanic cell is producing the ē [electrons]". A2 and A3, did not try to answer the question in the posttest, suggesting that the conceptions are not intelligible and plausible to them even though they had attended a series of conventional lectures. When asked further in the interview:

A2's responses:

Researcher: *Why did you think that cathode (in electrolytic cell) is a negative terminal?*

A2: *Because it has a lot of electrons.*

Researcher: *Can you explain?*

A2: *Electrons have negative charge…*

Researcher: *What about Galvanic cell?*

A2: *Emmm…it should be reversed.*

A3's responses:

Researcher: *Which are the anode and the cathode?*

A3: *This is cathode because it is negative*
Researcher: *Anode?*

A3: *Anode is positive electrode…*

Researcher: *Which electrode is anode or cathode (Galvanic cell)?*

A3: *Copper is anode.*

Researcher: *Why?*

A3: *Anode…positive electrode*

Both A2 and A3 associated the cathode with the negative and positive electrode, respectively. They knew that the electrodes in a Galvanic cell have opposite charges but failed to explain further. This confusion suggests that the conceptions are not intelligible and plausible to them even though they had attended a series of conventional lectures. All subjects in the CLI group gave correct answers on the surface or symbolic level of conception but failed to understand the macroscopic and microscopic explanation of the concepts. This suggested that the subjects in the CLI group experienced a weak conceptual change progression.

CAnI Group: B1, B2 and B3

In the pretest only B1 and B3 tried to answer Question 4. B1 wrote that "molten KCl is negatively charged because it gains electrons from anode" which is incorrect and meaningless because molten KCl is not a cathode. Meanwhile, B3 wrote that cathode in molten KCl cell is negative because "K [sodium] is on the top of the Chemical Reaction Series [the Electrochemical Series] …. Zn-Cu below the Chemical Reaction Series". Again, B3 referred to molten sodium, K^+ and Zn-Cu as electrodes for both cells respectively. This answer shows that B1 and B3 did not possess fundamental understandings of electrolytic and Galvanic cells. They failed to recognise the electrodes and to distinguish them from electrolytes.

However, in the posttest B1 and B2 provided correct answers while B3 got it partially correct. B1 wrote that the cathode in the electrolysis cell of molten $PbBr_2$ is negatively charge because "it contain excess electrons…the battery will flow the electrons" while the cathode in Galvanic cell is positively charged because "it give ē [electrons]".

B2 gave the answer that the cathode in the electrolysis cell of molten $PbBr_2$ is negatively charged because "it accepts/gains electron from the battery" while the cathode in the Galvanic cell is positively charged because "it releases the electron". B3 explained that the cathode in electrolytic cell is negatively charged because "cathode is connected to the negative part [of the battery].

B1, B2 and B3 seemed to understand the reason why the cathode in the electrolytic cell is negatively charged, but they failed to explain completely why the cathode in the Galvanic cell is positively charged. However, all of them gave the correct answers for the electrolytic cell, suggesting that they experienced better conceptual change progress. For example, when asked further in the interview, B1 explained:

Researcher: *What makes you choose the electrode as negative electrode?*

B1: *It is connected to the battery…which flow charges*

Researcher: *The battery flow charges?*

B1: *The battery flow the electrons….then…plumbum receives the electrons*

Question 5

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

Question 5 examines the concept that the more active a metal, the greater is its tendency to release or donate electrons (to oxidise). The activity of metals is ordered in the Electrochemical Series and may be accordingly used to determine the anode (more active) and cathode (less active) for a Galvanic cell. The three possible sequence of conceptual set for this question is:

Active metal: Easy to release electrons ↔ Oxidation (reducing agent) ↔ Anode

CLI Group: A1, A2 and A3

There was no response at all in the pretest for this question. A1, A2 and A3 probably did not have any idea how to apply the activity of metals for determination of anode or cathode.

Surprisingly, all of them gave correct answers in the posttest. They recognised the anode based on different features. A1 associated anode with "giving out electrons" while A2 and A3 associated anode with "reducing agent" without further explanation. No one related activity of the metal with the preference to lose electrons or preference to undergo oxidation as a basis of their explanation. This suggests that the conceptions underlying the question are intelligible but are not considered as a plausible idea. It also suggests that subjects in the CLI group experienced weak conceptual change progress.

CAnI Group: B1, B2 and B3

In the pretest, B1, B2 and B3 gave completely wrong and irrelevant explanations even though they tried to answer the question. These initial answers showed that they did not understand the concept of anode. However, in the posttest, all of them got the correct answer.

B1's, B2's and B3's responses show evidence of conceptual change. B1 recognised the anode based on the logical possible ideas that active metals prefer to release electrons and undergo the process of oxidation. For example in the interview, she repeated the answer why she chose zinc as electrode anode:

Researcher: *Which is anode?*

B1: *Zn….Zn more reactive*

B2 gave a straightforward answer that the anode donates electrons. She gave a more detailed explanation in the interview. B2's responses:

Researcher: *Why did you chose Zn* $^{2+}$ *releasing electrons and Cu receiving electron?*

B2: *Zinc is located at higher position in the electrochemical series…so zinc is electropositive….*

Researcher: *Please explain your answer, why reactive metal tend to be an anode?*

B2: *Reactive metal…..more electropositive…*

Researcher: So?

B2: *It tend to release electrons…*

Researcher: *Then…?*

B2: *Wait……donate means oxidation….oxidation means anode….*

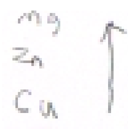
B3 chose to explain that active metals are strong reducing agents and therefore undergo oxidation. In the interview, she explained:

Researcher: *Which substance undergoes oxidation?*

B3: *Zinc.*

Researcher: *Why?*

B3: *Zinc is located above copper in the Series of Electrochemistry*



Researcher: *What does it mean?*

B3: *Zinc is more reactive*

Thus, the concept of anode for the Galvanic cell seems intelligible and plausible for B1, B2 and B3. A strong conceptual change process is believed to have occurred as B1, B2 and B3 correctly explained why in a Galvanic cell, the more active (reactive) metal is more likely to be the anode in comparison to their counterparts in the CLI group.

CONCLUSION

Most interviewees retained only a small amount of knowledge regarding electrochemistry conceptions before attending the instruction and therefore failed to respond successfully in the pretest. It is believed that the interviewees possessed little understanding of the topic taught to them during their secondary level studies. Pretest analysis shows that most interviewees left the questions unanswered or answered with erroneous conceptions. However, the study found that interviewees in both groups succeeded in answering questions of low-level cognitive domain in the posttest.

Despite the incompleteness of their answers in the posttest, the subjects in the CLI group had problems elaborating the underlying processes at both microscopic and macroscopic levels during the interview sessions. This suggests that they experienced only weak rather strong conceptual change progress. The complex, abstract and dynamic conceptions within the redox process remained unintelligible and implausible to them even after attending the series of lectures. The posttest answers and the responses during the interview session, show that subjects in the CAnI group were able to provide better explanations of the complex, abstract and dynamic conceptions. This indicates that they experienced a strong conceptual change process.

In summary, it can be concluded that after exposure to a series of lectures on electrochemistry, targeted conceptions were found to be more intelligible and plausible to the subjects in the CAnI group in comparison to their counterparts in the CLI group. It appears both groups experienced weak conceptual change, while the former significantly outperformed the latter in experiencing strong conceptual change. It is hoped that this analysis lends support and invites further study into implementation of the CAnI method as an ICT rich alternative to conventional lecture format.

REFERENCES

Berg, B.L. (2001). *Qualitative Research Methods for the Social Sciences*. Boston: Allyn and Bacon.

Byrne, M.D., Catrambone, R. and Stasco, J.T. (1999). Evaluating animations as students aids in learning computer algorithms. *Computers and Education,* 33, 253-278.

Chi, M.T.H., Slotta, J.D. and deLeeuw, N. (1994). From things to processes: A theory of Conceptual Change for Learning Science Concept. *Learning and Instruction.* 4, 27-43.

Chi, M.T.H. and Roscoe, R.D. (2002). The processes and challenges of conceptual change. In M. Limon and L. Mason. (eds) *Reconsidering Conceptual Change. Issues in Theory and Practice,*(pp.3-27). Netherlands: Kluwer Academic Publishers.

Duit, R. and Treagust, D.F. (2003). Conceptual change: A powerful framework for improving science teaching and learning. *International Journal of Science Education,* 25(6), 671-688.

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), pp. 355-385.

Greenbowe, T.J. (1994). An interactive multimedia software program for exploring electrochemical cells. *Journal of Chemical Education,* 71, 555-557.

Jimoyiannis, A. and Komis, V. (2001). Computer simulations in physics teaching and learning: a case study on students' understanding of trajectory motion. *Computers and Education,* 36, 183-204.

Kidder, L.H. and Judd, C.M. (1986). *Research Methods in Social Relations*. New York: Holt, Rinehart and Winston.

Lee, G., Kwon, J. and 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.

Maier, P., Barnett, L., Warren. A. and Brunner, D. (1998). *Using Technology in Teaching and Learning*. London: Kogan Page.

McNaught, C. (1996). The nature of IT and its implications for practices and policy in higher education. Paper presented at the Annual Conference of Australian Society of Computers in Learning in Tertiary Education, University of South Australia.

Michael, K.Y. (2001). The effect of a computer simulation activity versus a hands-on activity on product creativity in technology education. *Jounal of Technology Education,* 13(3), 31-43.

Milrad, M. (2002). Using construction kits, modelling tools and system dynamics simulations to support collaborative discovery learning. *Educational Technology & Society,* 5(4), 1-18.

Neo, M. and 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.

Osborne, R.J. and Freyberg, P. (1985). *Learning in Science: The Implication of Children's Science*. London: Heinemann Educational Books.

Posner, G.J., Strike, K.A., Hewson, P.W. and 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. and Chen, Q. (2003). Supporting scientific discovery learning in a simulation environment. *Journal of Computer Assisted Learning,* 19, 9-20.

River, R.H. and Vockell, E. (1987). Computer simulations to stimulate scientific problem solving. *Journal of Research in Science Teaching,* 24, 212-234.

Ronen, M. and Eliahu, M. (2000). Simulation - A bridge between theory and reality: The case of electric circuit. *Journal of Computer Assisted Learning,* 16, 14-26.

Strike, K.A. and Posner, G.J. (1992). A revisionist theory of conceptual change. In D.R. and H.R. Albany, (eds) *Philosophy of Science, Cognitive Psychology, and Educational Theory and Practice,* (pp.147-176). SUNY Press.

Sung, W.T. and 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.

Tao, P.K. and 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.