Effectiveness of interactive multimedia module with pedagogical agent (IMMPA) in the learning of electrochemistry: A preliminary investigation

Tien Tien LEE
Faculty of Science & Mathematics, Universiti Pendidikan Sultan Idris, 35900 Tanjong Malim, Perak, MALAYSIA
E-mail: tientien@upsi.edu.my

and

Kamisah OSMAN
Faculty of Education, Universiti Kebangsaan Malaysia, 43600 Bandar Baru Bangi, Selangor, MALAYSIA
E-mail: kamisah@ukm.my

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Contents

Abstract

Electrochemistry is found to be a difficult topic to learn due to its abstract concepts that involve the macroscopic, microscopic and symbolic representation levels. Research showed that animation and simulation using Information and Communication Technology (ICT) can help students to visualize and hence enhance students' understanding in learning abstract chemistry topics. As a result, IMMPA named EC Lab was developed in order to assist students in the learning of the Electrochemistry topic. A preliminary investigation was carried out in a secondary school involving 35 students to test on the usability of the module developed. Instruments involved were pretest, post-test and a motivation questionnaire. Results showed that the students have higher scores on their post-test as well as gained higher motivation level after learning with the EC Lab.

Introduction

Electrochemistry is the sixth chapter in the Malaysian Chemistry syllabus for secondary schools. This chapter is taught at the upper secondary level for students in the science stream. Electrochemistry is a study of inter-conversion of chemical energy and electrical energy that occurs in electrolytic and voltaic cell. Previous studies (Bojczuk, 1982; Lee & Kamisah, 2010; Lin *et al.*, 2002; Roziah, 2005) showed that the topic is difficult to learn because the concepts are abstract. Students often encounter misconceptions in the learning of this topic (Garnett & Hackling, 1993; Garnett & Treagust, 1992; Garnett, Garnett & Hackling, 1995;

Karsli & Çalik 2012; Lee & Mohammad Yusof, 2009; Lee, 2008; Lin *et al*., 2002; Sanger & Greenbowe, 1997a; Sanger & Greenbowe, 1997b). Macroscopically, students need to study the concepts of electrolytes and non-electrolytes, the electrolysis process and voltaic cells. Microscopically, they need to understand the movement of ions and electrons during the electrolysis process. Besides that, they need to transform the process into chemical formulae and equations symbolically. Students face difficulties in understanding the abstract chemical processes especially at the microscopic and symbolic levels (Garnett & Hackling, 1993; Garnett & Treagust, 1992; Garnett *et al*., 1995; Karsli & Çalik 2012; Lee & Mohammad Yusof, 2009; Lee, 2008; Lin *et al*., 2002; Sanger & Greenbowe, 1997a; Sanger & Greenbowe, 1997b).

Chemistry is a visual science (Wu & Shah, 2004). A major problem for students in learning abstract chemistry topics is their inability to visualize the concepts, which is to form a mental image or picture in the mind (Lerman, 2001). Studies (Doymus, 2010; Gois & Giordan, 2009; Karsli & Çalik 2012; Lerman & Morton, 2009) have been carried out and results showed that animation and simulation using ICT can help students to visualize and hence enhance their understanding in learning abstract chemistry topics. Therefore, designing instructions using multimedia through World Wide Web, CD-ROMs, DVD and virtual reality becomes a trend in this era of ICT.

Although the use of multimedia modules is able to assist students in visualizing the abstract concepts, the rate of using multimedia modules in the schools is still very low (Lee & Kamisah, 2010). Teachers are not interested in using the modules available in the market in the learning process because they find that these modules are too formal, not interesting and do not follow the syllabus (Norsiati, 2008; Roziah, 2005). Furthermore, students lack sufficient metacognitive awareness and comprehension monitoring skill to make effective choices (Hill & Hannafin, 2001; Land, 2000). They lack the skills to find, process and use information and ideas. Students as novice learners do not always make connections to prior knowledge or everyday experiences in ways that are productive for learning (Land, 2000). As a result, Pedagogical Agents (PAs) are designed to facilitate learning in computer-mediated learning environments (Chou, Chan & Lin, 2003; Craig, Gholson & Driscoll, 2002; Johnson, Rickel & Lester, 2000; Moundridou & Virvou, 2002; Predinger, Saeyor & Ishizuka, n.d., Slater, 2000). The use of PAs in the interactive multimedia module in this study makes the module different from the modules available in the market.

PAs are animated life-like characters that show human characteristics in terms of appearance such as changes in facial expressions, gestures and body movements when interacting with the users. Users can communicate with the agent via speech or on-screen text. The appearance of PAs is varied in terms of gender (male or female), realism (cartoon and realistic) and ethnicity (African-American and Caucasian) (Baylor, 2005). Normally, PAs are designed as experts (Baylor, 2005; Baylor & Kim, 2004; Chou *et al*., 2003; Hayes-Roth, Maldonado & Moraes, 2002; Kim, Baylor & PALS Group, 2006; Kizilkaya & Askar, 2008; Moreno, Mayer & Lester, 2000; Moreno & Mayer, 2005) who are knowledgeable in specific areas to provide guidance to students. However, there are also PAs which act as co-learners (Chou *et al*., 2003; Kim *et al*., 2006; Maldonado & Hayes-Roth, 2004; Maldonado *et al*., 2005; Xiao, Stasko & Catrambone, 2004) or motivators (Baylor, 2005; Baylor & Kim, 2004; Kizilkaya & Askar, 2008). The co-learners or motivators accompany the students, encourage and motivate them to be involved in the learning process.

PAs in multimedia module serve to enhance students' metacognitive awareness of what they know and what they should know for the topic being studied. One strategy for providing metacognitive guidance involves embedding support, or scaffolds for procedural, strategic, or metacognitive control (Land, 2000). This guidance and support is provided by the PAs in the module. PAs could make learners aware of the opportunities presented to them, provide advice for the learners on the tools to be used, and explain the functionalities of the tools in an open learning environment (Clarebout & Elen, 2007).

Studies abroad were carried out by several research groups using PAs in multimedia software for a variety of subjects such as environmental sciences (Moreno & Mayer, 2000), language (Maldonado *et al*., 2005; Predinger *et al*., n.d.), ecosystem (Biswas *et al*., 2004), art (Hayes-Roth *et al*., 2002), ecology (Clarebout & Elen, 2007), mathematics (Kim *et al*., 2006; Atkinson, 2002) and space (Kizilkaya & Askar, 2008). In Malaysia, studies relating to PAs have been done in Islamic Education (Mohd Feham, 2006) and Physics Education (Farah *et al*., 2008; Nabila Akbal *et al*., 2008). Studies conducted by Kirk (2008) and Baylor (2005) give students the freedom to choose their preferred PAs to assist them in the learning process. However, these agents were designed to differ only in terms of appearance (the image of an anthropomorphic pig, a green alien, and a robot), gender (male and female), ethnicity (African-American and Caucasian) and realism (real or cartoon), but were similar in terms of role. Studies on electrochemistry and the freedom to choose different roles of PAs still cannot be found. Hence, an interactive multimedia module with pedagogical agents (IMMPA) with different roles of PAs, named EC Lab was developed in order to assist students in the learning of Electrochemistry.

Methodology

Sample

35 Form Four students were selected as the sample for the pilot study in order to investigate the effect of EC Lab on the students' knowledge and motivation in the learning of Electrochemistry. The sample consisted of 13 male and 22 female students (aged 16 years), and the majority of them are Malays.

Materials

Materials utilized in the study are the specific entry test, pretest, post-test, motivation questionnaire and the IMMPA titled EC Lab. The specific entry test consists of ten multiple choice questions testing on some basic skills that will be applied in the learning of Electrochemistry. The purpose of the specific entry test is to identify students' specific entry competencies related to proton number, nucleon number, arrangement of electrons, chemical formulae and chemical equation. Students were given the chance to recall their prior knowledge on the related basic skills before they start the intervention. Achievement tests were administrated in the form of pretest and post-test before and after the intervention. There are two structured questions in the achievement test. The questions test knowledge on electrolytic cell and voltaic cell concepts at the macroscopic, microscopic and symbolic levels. Macroscopically, the students need to identify the anode and cathode in the cell and describe the observations at both electrodes during the electrolysis process. Microscopically, they need to draw the ions that exist in the electrolyte and the direction of the flow of the electrons in the circuit. Symbolically, they have to represent the oxidation and reduction process at the electrodes by writing the half-equations. Questions in the pretest and post-test are similar in terms of difficulty level and concepts tested. The only difference is the types of electrodes and electrolyte used in the cells. Reliability analysis was carried out and the Kuder Richardson KR-21 reliability index is 0.65 for the pretest and 0.71 for posttest.

The motivation questionnaire is a Likert scale questionnaire. There are three sub dimensions involved, namely Adhered Value, Expectancy Components and Affective Components**.**Adhered Value consists of three constructs, namely intrinsic goal orientation, extrinsic goal orientation and task value. On the other hand, Expectancy Components consist of control of learning belief construct and self-efficacy for learning and performance construct. Affective Components involve test anxiety construct. There are 28 items in the questionnaire with Likert scale provided, where 1 – Strongly Disagree, 2 – Disagree, 3 – Not Sure, 4 – Agree, and 5 – Strongly Agree. Items in the questionnaire have been taken from the study of Sadiah and colleagues (2009) which were translated from the instrument used by Pintrich and DeGroot (1990). In this study, the researcher used the motivation section only and changed the scale from seven points to five points. The Cronbach Alpha for the motivation questionnaire is 0.87.

EC Lab was developed by the researcher by using the combination of two instructional design models: the Kemp Model and Gerlach and Ely Model. The reasons for using the combination of these two models are because they are classroom-oriented models (Gustafson & Branch, 1997) with their own strengths. The Kemp Model describes elements, not 'step, stage, level or sequential item' in an instructional design (Kemp *et al.*, 2004). The oval shape of the model indicates the independency of the elements in the model. It is a non-linear model with no starting and ending point. All the processes of designing, developing, implementing and evaluating can be done concurrently and continuously. The Gerlach and Ely Model is suitable for the novice instructional designers who have knowledge and expertise in a specific context (Qureshi, 2001, 2003, 2004). This model is classroom-oriented and is suitable for teachers at secondary schools and higher education institutions. The Gerlach and Ely Model focus more on the instructional materials and resources without identifying the instructional problems. Hence, the researcher combined the two models as the instructional design model to develop the EC Lab. The conceptual framework of the combination of these two models used in the study is presented in the Appendix.

There are two PAs in the EC Lab, namely Professor T and Lisa. Professor T is a sixty year-old male PA who acts as an expert in Electrochemistry. He gives accurate information and explains new concepts to the students. Professor T speaks slowly in a formal way with little body gestures and facial expressions. On the other hand, Lisa is a fifteen-year old female youth who speaks with an energetic voice. She is a learning companion in the EC Lab. She learns together with the students, gives motivation and encouragement to the students to complete the tasks and exercises in the module. Students are free to choose the PA they want to accompany them in the learning of Electrochemistry when using the EC Lab.

The main menu for the EC Lab consists of tutorial, experiment, exercise, quiz, memo and game. There are five sub units in the EC Lab: (1) Electrolytes and Non-Electrolytes, (2) Electrolysis of Molten Compounds, (3) Electrolysis of Aqueous Solutions, (4) Voltaic Cells and (5) Types of Voltaic Cells. All the information delivery for the sub units are presented in the tutorial session. The experiment session consists of five experiments in Electrochemistry. The first experiment about the concept of electrolyte and non-electrolyte is done through the application of simulation. Another three experiments investigating the factors that determine the ions to be discharged at the electrodes and experiment for simple voltaic cell are hands-on investigation. The students are guided by the PAs to carry out the experiments in the chemistry laboratory and they need to apply scientific process skills and manipulative skills in order to carry out the investigations. After the information delivery process, the students will do some exercises to enhance their understanding on the concepts learnt. A quiz will be given at the end of every sub unit. Each quiz is divided into three levels. The first level is to let the students do some reflections on what they have learnt in the sub unit. The students then need to compare their prior idea with the new idea to review whether the conceptual change has occurred. The second level of the quiz consists of five simple multiple choice questions and some elementary structured questions. The third level of the quiz is more challenging with some difficult structured questions and essays. Memo is created to give some hints and tips on learning of some of the Electrochemistry concepts. For instance, mnemonics are given to help the students in memorizing the list of anions and cations in the Electrochemical Series. There are four activities in the game session to let the students relax their mind after the learning process. The activities are applications of Electrochemistry concepts; for instance, one of the activities asks the students to set up an electrolytic cell and a voltaic cell with the apparatus given.

The complete flow of each sub unit follows the five phases in the learning process created by Needham (1987). The five phases are orientation, elicitation of ideas, restructuring of ideas, application of ideas and review. In the EC Lab, the *Think About It* session (Figure 1) is the orientation phase. The students will be shown some pictures that are familiar to them. Those pictures are related to the concepts to be learnt in every sub unit.

Figure 1. Think about it session in orientation phase

Then, in the *Do You Still Remember?* session, the students will be reminded of some concepts that they have learnt before. Those concepts are related to the new concepts to be learnt in the sub unit. Next, in the *Give Me Your Ideas* session, the students are given the chance to give their ideas regarding some activities that are related to the concepts to be learnt. Then, in the *Are You Sure?* session, the students need to give some ideas, make some guesses or predictions on some outcomes of the situations. In order to examine their ideas, guesses and predictions, the students need to carry out some investigations in *Let's Do It* (Figure 2) or watch related videos in *Show Time* sessions. In these two sessions, the students will be exposed to the conflict situations if their ideas, guesses or predictions are different from what is being shown in the experiments or videos. Hence, conceptual change should happen here and the students need to modify, extend or replace their existing ideas.

Figure 2. Simulation activity in Let's do it session

Then, reinforcement of the constructed ideas will be done in the *Practice Makes Perfect* session. The students will apply the concepts learnt in new situations and examples. Lastly, *Before and After* session (Figure 3) is created to enable the students to reflect upon the extent to which their ideas have changed. The students need to answer certain activity questions again and compare their prior answers to the new answers. *Testing Yourself* and *Challenge Yourself* sessions contain multiple choice questions, structured questions and essay questions to let the students evaluate themselves on the concepts learnt.

Figure 3. Before & after session in review phase

Procedure

The samples were given the specific entry test, pretest and motivation questionnaire to study their existing knowledge in Electrochemistry and their motivation level in studying Chemistry. The students were given 80 minutes to answer the specific entry test, pretest and motivation questionnaire. The students who had poor results for the specific entry test were given some revision notes. They were told to study the revision notes before the treatment sessions. The second meeting was carried out after the school session where the students were gathered at the computer laboratory. Students need to put on the earphone to listen to the script delivered by the PAs. The user manual was given to the students, followed by a briefing on how to use the EC Lab. Then, students were free to explore the first and second sub unit in 160 minutes. The third and forth meeting were conducted at the chemistry laboratory to carry out the experiments investigating the factors that determine the ions to be discharged at the electrodes for the third sub unit. The principal of the school limited the duration of the pilot study to four meetings; hence, the students only studied three sub units in the EC Lab. They only studied the concept of electrolytic cell. After the investigations, the students were given the post-test and motivation questionnaire, and they were asked to answer these instruments in 80 minutes.

Analysis of data

The specific entry test, pretest and post-test were marked according to the answer scheme developed. Each correct answer was given one point while the wrong answer was given zero point. Then, the pre and post motivation questionnaires were analyzed by using SPSS version 18.0 to find out the mean values for each construct. Paired-sample t-test was conducted to evaluate the impact of the EC Lab on the students' achievement test and motivation level.

Results and discussion

Specific Entry Test

The pilot study was carried out after the students had been taught Electrochemistry by their Chemistry teacher. Hence, the researcher assumed that the students have already had some existing knowledge regarding the basic concepts of electrolytic cell. The researcher expected to get moderate performance from the students for the specific entry test and pretest since they had already learnt the topic. Surprisingly, the students' results were very poor. Half of the students failed the specific entry test and all of them failed the pretest.

Marks (per 100)	Frequency (n)	Percentage (%)
10	2	5.7
20	7	20.0
30	8	22.9
40	6	17.1
50	5	14.3
60	6	17.1
70	1	2.9
Total	35	100.0

Table I: Students' results for the specific entry test

Specific entry competencies are prerequisite knowledge, skills and attitudes that learners must possess to benefit from the training (Morrison, Ross & Kemp, 2007). The specific entry test in this study tested the students on some basic knowledge and skills that they have to master before they study Electrochemistry. The basic knowledge and skills are related to proton number, nucleon number, arrangement of electrons, chemical formulae and chemical equation. They need to have the skills to write chemical formulae and chemical equations in describing the process that takes place in the electrolytic cells. The students' results ranged from 10% to 70%. The results showed that the students were still weak in writing chemical formulae (Item 2, only 22.9% of the students answered correctly and for Item 8, only 17.1% of the students answered correctly) and the concept of proton number (Item 9, only 20.0% of the students answered correctly). The students who failed the specific entry test were given remedial help before they started with the treatment sessions. They were given some revision notes for Chapter two – The structure of atom and Chapter three – Chemical formulae.

Achievement Test

Achievement tests were given in the form of pretest and post-test before and after the intervention to study the effect of IMMPA EC Lab on students' understanding in Electrochemistry. Table II below shows the t-test results for the pretest and posttest.

Test	N	Mean	Std. Deviation	t value	Sig (2-tailed)
Post test	35	26.98	13.61	8.97	0.000*
Pre test	35	9.42	5.71		

Table II: t-test table for the students' achievement tests

A paired-sample t-test was conducted to evaluate the impact of the IMMPA EC Lab on the students' scores in the achievement test. There is a statistically significant increase in the achievement test from the pretest ($M = 9.42$, $SD = 5.71$) to the post-test [$M = 26.98$, $SD = 13.61$, $t(34) = 8.97$, $p < 0.05$]. The magnitude of the difference in the means is very large (eta squared = 0.5419) (Cohen, 1988). Although the overall results for the post-test are better compared to the pretest, 85.7% of them still failed the posttest. The results for the posttest ranged from 3.70% to 77.78%.

The students were still weak in certain concepts in Electrochemistry especially at the microscopic and symbolic levels. For instance, the students still cannot differentiate between the flow of electrons in the conductors and the flow of ions in the electrolytes (Lee & Mohammad Yusof, 2009; Lee, 2008; Özkaya, Üce & ?ahin, 2003; Sanger & Greenbowe, 1997a). Only 14.3% of the students can answer Item 1 c (i) which asked the students to draw the direction of the flow of electrons in the electrolytic cell. The majority of the students drew the electrons in the electrolyte (see Figure 4) and some of them drew the electrons in the opposite direction. However, students' results showed increment from pretest (2.9%) to post-test (14.3%) in this item indicating that the animations in the *Micro-World* help to assist the students in understanding the movement of electrons microscopically.

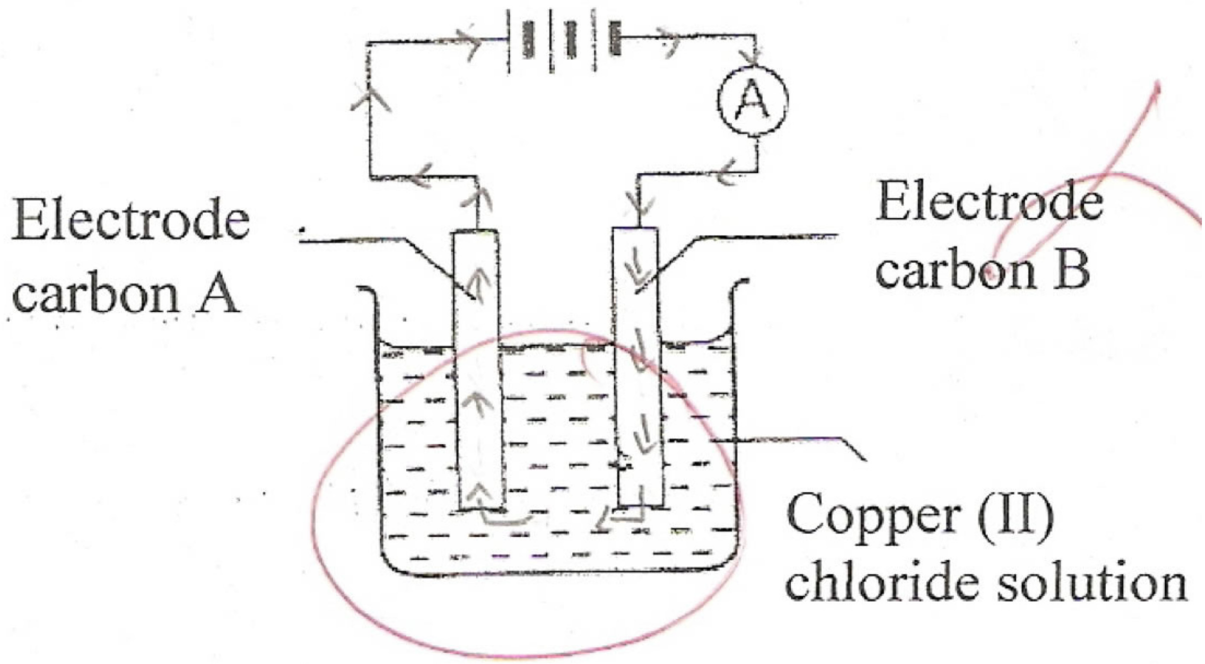

Figure 4: Electrons flow in electrolyte

The students were also confused between the processes that happened at the anode and cathode during the electrolysis process. Students always assume that anions will be attracted to the cathode while cations will be attracted to the anode (Lee & Mohammad Yusof, 2009; Lee, 2008). This is because anions are negative ions and the students in this study assumed that negative ions will be attracted to negative electrode and vice versa. The students' misconceptions of this concept were revealed in Item 1 e (i) and (ii). About 22.9% of the students answered both questions correctly in the post-test compared to only 2.9% of them answered correctly during the pretest.

The students were also confused about which ions are to be discharged at the electrodes. They cannot determine the factors to be considered when they answered the question. For instance, the students need to consider the effect of the concentration of ions to determine the ions to be discharged at the electrodes for Item 1 l. However, the majority of them failed to give the correct answer. Only 5.7% of them could give the correct observation at the anode and only 17.1% of them could give the correct observation for the colour change in the cell. Some of the students could give the correct observations at the electrodes, but they failed to give the reasons for their answers.

Overall, students' conceptions improved after the intervention especially in microscopic and symbolic levels. Descriptions of students' answers for some Electrochemistry concepts during the pretest and posttest are presented at Table III below.

Electrochemistry concepts	Pretest's answers	Posttest's answers
The flow of current in the conductors and in the electrolytes [Item 1 c (i)]	• Electrons flow in electrolyte • Electrons flow from cathode to anode • Electrons come out from both electrodes	• Electrons flow from anode to cathode
Process at the anode and cathode [Item 1 e (i), 1 e (ii)]	• Anions accumulated at cathode • Cations accumulated at anode • Absence of ions from water molecule	• Anions accumulated at anode • Cations accumulated at cathode • H+ ions and OH- ions are included in the answers
Concepts of oxidation and reduction process at the electrodes [Item 1 g (i), 1 g (ii)]	• Oxidation equation at cathode • Reduction equation at anode • Wrong / incomplete half equations	• Oxidation equation at anode • Reduction equation at cathode • Correct and complete half equations

Concept of electrolyte [Item 1 d]	• Absence of ions from water molecule in the electrolyte	• H+ ions and OH- ions are present in the electrolyte

Table III: Comparison of students' answers for pretest and posttest

Motivation Questionnaire

The motivation questionnaire was used to assess the students' goals and value beliefs for Chemistry (especially Electrochemistry), their beliefs about their ability to succeed in the subject and their anxiety toward the test and examination on Electrochemistry. Constructs involved are intrinsic goal orientation, extrinsic goal orientation, task value, control of learning belief, self-efficacy for learning and performance and test anxiety. Table below shows the t-test result for the motivation questionnaire in the study.

Questionnaire	N	Mean	Std. Deviation	t value	Sig (2-tailed
Post	35	3.68	0.34	2.42	0.021*
Pre	35	3.53	0.32		

Table IV: t-test table for the students' motivation level

Table IV shows that there is a statistically significant increase in the level of motivation from the pre-questionnaire (M = 3.53, SD = 0.32) to the post-questionnaire [M = 3.68, SD = 0.34, t(34) = 2.42, $p < 0.05$]. The eta square is 0.079, which is considered as a moderate effect size (Cohen, 1988). Overall, the students' motivation level increased for each construct in the motivation questionnaire except for the test anxiety construct which maintained the same. The mean value for Self-efficacy for learning and performance construct showed the biggest increase from 3.30 (SD = 0.42) to 3.54 (SD = 0.50) after the students studied with the EC Lab. Self-efficacy refers to personal beliefs about having the means to learn or perform effectively (Zimmerman, 2000). High self-efficacy beliefs enable the students to be more motivated to learn Electrochemistry and hence their test anxiety level is low (M = 2.06, SD = 0.67). High self-efficacy values are related to relatively high intrinsic motivation values. In this study, the students' intrinsic goal orientation value is 3.84 (SD = 0.48), showing that the students enjoyed learning with the EC Lab. The variety of feedback given by the PAs and the videos shown during the discussions attracted the students' attention to study the topic. The students showed the highest extrinsic goal orientation (M = 4.54, SD = 0.40) among all the constructs, indicating that they were trying to show to others that they can perform well in Chemistry.

Conclusion

The result from this pilot study showed that the IMMPA EC Lab was able to increase the students' score in the achievement test as well as their motivation level in the learning of Electrochemistry. This is parallel with studies abroad (Johnson et al., 2000; Kizilkaya & Askar, 2008; Moundridou & Virvou, 2002; Moreno et al., 2000) where students were found to be more motivated and interested, and achieve higher performance when learning with tutorial supported by PAs. However, this pilot study was just a preliminary investigation involving only a small group of students. The actual study in the form of quasi-experimental design involving more students will be conducted to investigate the effectiveness of the IMMPA EC Lab on students' knowledge and motivation.

IMMPA EC Lab in this study is an interactive multimedia module developed by following the combination of two instructional design models. The combination of the Kemp Model and Gerlach and Ely Model overcomes the weaknesses of the two models and produced a stronger instructional design model. One hopes that the combination of the models used in this study will benefit the researchers in developing instructional materials. The implementation of PAs in multimedia modules in Electrochemistry was proven to increase students' knowledge and motivation level in the learning of Chemistry. This is a new trial in Malaysian Chemistry Education and it is hoped that the use of PAs in multimedia module can be applied in other Chemistry topics in the syllabus. Undeniably, studies regarding PAs have been carried out by researchers abroad, but this type of research is still new among researchers in East-Asia. Hence, studies associated with PAs should be increased, to involve various fields and applied in various stages of education to benefit students from diverse backgrounds.

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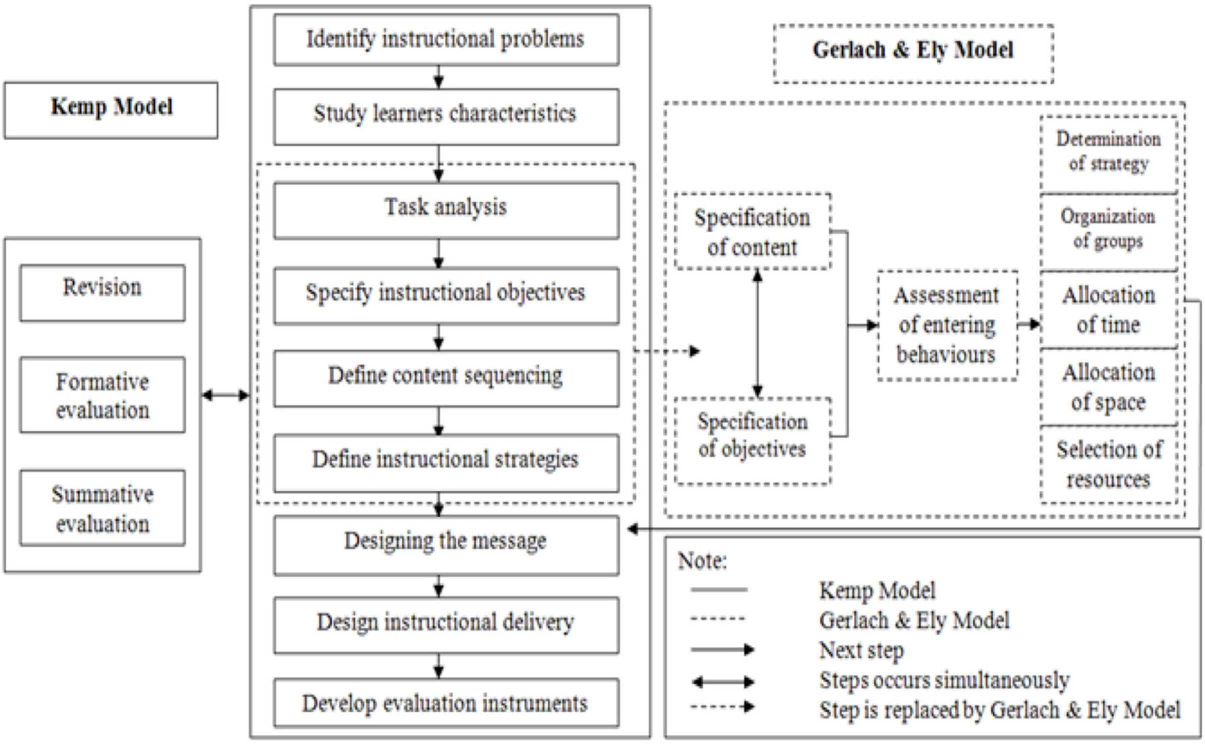
Appendix


Kemp Model
Identify instructional problems
Study learners characteristics
Task analysis
Specify instructional objectives
Define content sequencing
Define instructional strategies
Designing the message
Design instructional delivery
Develop evaluation instruments
Revision
Formative evaluation
Summative evaluation
Gerlach & Ely Model
Specification of content
Specification of objectives
Assessment of entering behaviours
Determination of strategy
Organization of groups
Allocation of time
Allocation of space
Selection of resources
Note:
Kemp Model
Gerlach & Ely Model
Next step
Steps occurs simultaneously
Step is replaced by Gerlach & Ely Model