Improving Students' Conceptual Understanding of a Specific Content Learning: A Designed Teaching Sequence

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22-May-2012

ABSTRACT

The efficacy of a teaching sequence designed for a specific content of learning of electrochemistry is described in this paper. The design of the teaching draws upon theoretical insights into perspectives on learning and empirical studies to improve the teaching of this topic. A case study involving two classes, the experimental and baseline classes was carried out for 16-year-old Malaysian upper secondary school students. In addition, eight classes of similar age in eight different schools served as convenience samples (reference groups) were selected in order to compare the differences on their conceptual understanding in a wider sample. The evaluation of students' responses in one of the items in the post diagnostic test shows that there were significant differences in the experimental class students' performances in comparison to the baseline class students and the convenience samples. The finding indicates that the tools designed in the teaching sequence are able to be utilized in the classroom teaching for a specific content of learning.

Keywords: *Electrochemistry, electrolytic cell, teaching sequence, social constructivism*

INTRODUCTION

Electrochemistry has been widely reported as being one of the most difficult topics in chemistry because it contains many ambiguous and abstract terms and has an apparent lack of consistency and logic in its representation (Sanger & Greenbowe, 1997a & 1997b; Ozmen, 2004; Ozkaya et al., 2006; Schmidt et al., 2007). Some teachers find the topic difficult to teach and reason that the lesson plans are hard to prepare (Ahtee et al., 2002). Terms like 'ions,' 'atoms,' 'electrons,' 'equilibrium,' and 'delocalise' have no precise meaning in everyday life, but pose a defined meaning in chemistry. These terms are initially introduced by teachers, as students do not just discover the terms or concepts by themselves.

Electrochemistry is the study of the inter-conversion of electrical and chemical energy which involves many examples of chemical observations, chemical reactions and symbols. There are two main electrochemical cells: the electrolytic and voltaic (galvanic) cells. These two cells have similar related features such as having two electrodes that are dipped into a solution known as electrolytes, and these two electrodes are connected to positive and negative terminals. Even though both electrochemical cells have similar terminologies, but the outcomes for their chemical changes and reactions are different from one another. For example, in the electrolytic cell, the 'positive terminal' is known as the 'anode', whilst in the voltaic cell, the 'negative terminal' is similarly known as the 'anode'. Thus, the statement found in the text book such as 'electrolytic cell is the reverse of the voltaic cell is an over generalised statement because not all features of both cells are the opposite of each other because the outcomes of the chemical changes and reactions and products at the electrodes are different.

It is found that students from different countries hold common difficulties due to many factors discussed above. The studies found are repetitious or are the replication of another; for example, Africa (Huddle & White, 2000; Ogude & Bradley, 1994 & 1996), America (Greenbowe, 1994; Sanger & Greenbowe, 1997a, 1997b, 1999, & 2000), Australia (Garnett et al., 1990; Garnett and Treagust, 1992a & 1992b), Belgium (Brandt et al., 2001), Finland (Ahtee et al., 2002), Germany (Schmidt & Volke, 2003; Schmidt et al., 2007), Jamaica (Thompson & Soyibo, 2002), Taiwan (Chou, 2002), Turkey (Ozkaya, 2002; Ozkaya et al., 2006), and Venezuela (Niaz, 2002; Niaz & Chacon, 2003). These studies suggest that throughout the world students generally have difficulties in learning electrochemistry; hence, further studies in this area

are required. Note that some of the studies are conducted and repeated by the same researchers, and research in this area seems to be less reported in the literature after 2007.

STATEMENT OF PROBLEM

Research in chemistry education has shown that students often have difficulty in understanding chemistry concepts due to their abstract nature and many attempts have been made by researchers to assist students' learning by identifying the difficulties experienced by students and possible solutions to overcome this problem (Sanger & Greenbowe, 1997a and 1997b; Niaz & Chacon, 2003; Ozmen, 2004; Ozkaya et al., 2006). There are three levels of representation of chemical phenomena: macroscopic, sub-microscopic and symbolic (Treagust et al., 2003). The macroscopic level is an observable chemical event, e.g. observing the production of a new substance. In order to communicate regarding this macroscopic event, chemists commonly use symbolic representations such as chemical equations, reactions mechanisms, models and many other techniques (Treagust et al., 2003). Treagust et al. further add that the sub-microscopic level of representation is usually based on the particulate theory of matter, where the sub-microscopic entities are real, but are too small to be observed.

Some existing studies provide instruction to teachers on how to teach electrochemistry, either suggesting teaching instructions or teaching activity on how to improve teaching and learning this topic, for example, using cooperative learning instruction (Acar and Tarhan, 2007), conceptual change instruction (Ozkaya et al., 2006), or computer animated instruction (Sanger and Greenbowe, 2000). However, to my knowledge, no specific study has suggested a teaching intervention that provides detailed explanation on how to produce a designed teaching sequence for specific content on this topic, which can be replicated following the Malaysian context and curriculum. Moreover, the studies reported in the literature often focus on students' understanding and difficulties in learning this topic (e.g. Garnett et al., 1990; Ozkaya, 2002); thus, a lack of attention is given to the issue above.

In addition, some studies on this topic focus more on the voltaic cell (e.g. Boulabiar et al., 2004; Morikawa & Williamson, 2001; Eilks et al., 2009), and others on comparing the chemical reactions in the electrolytic cell with the voltaic cell (Garnet & Treagust, 1992b; Sanger & Greenbowe, 1997b); however, not so many concentrate on the electrolytic cell itself (see Ahtee et al., 2002). Even though the structure, chemical changes and reactions of the voltaic cell are more complicated than the electrolytic cell; however, an understanding of the structure of the electrolytic cell and its related features serves as a starting point for students to understand the whole process of electrochemistry. Thus, students need to be well versed in and appreciate the structure, chemical processes and reactions of the electrolytic cell because it is introduced in the first part of the electrochemistry syllabus before the voltaic cell. Also, students often fail to relate macroscopic observation with sub-microscopic entities, and cannot represent the chemical changes and reactions using symbolic entities (e.g. half cell equation). Thus, teaching should be designed to improve the students' understanding of these aspects in particular.

THE LEEDS MODEL FRAMEWORK

The design of the teaching sequence followed a model framework based on the Leeds Model. In this model, Leach and Scott (2002, p.127) have outlined the following scheme as a guide to planning teaching interventions, as follows:
1. Identify the school science knowledge to be taught.
2. Consider how this area of science is conceptualized in the everyday reasoning of students.
3. Identify the learning demand by appraising the nature of any differences (conceptual, epistemological, and ontological) between (1) and (2).
4. Design the teaching intervention to address each aspect of this learning demand by:
    i. identifying the teaching goals for each phase of the intervention;
    ii. planning a sequence of activities to address the specific teaching goals;

iii. specifying how these teaching activities might be linked to appropriate forms of classroom communication.

According to Millar et al. (2006), when we are interested in improving the teaching and learning of 'X', what size should X be? They further add that this is an issue that needs to be raised before evidence-informed research is carried out. Thus, they state that a grain size could be the size of the 'units' of teaching and learning of X. Millar et al. believe that, in order to improve teaching and learning, we need to consider the smaller 'units' so that it is easier to identify the intended learning outcomes.

In addition, Leach and Scott (2008) state that, in designing a teaching sequence, features at both a large and fine grain size are important when designing teaching, as they address different levels and specificity in the teaching. For instance, at a large grain size, the conceptual framework of the social constructivist perspective on learning is presented where it is used to promote inquiry as a general pedagogic strategy, whilst at a fine grain size, this theory (social constructivism) is used to inform a specific pattern of teacher-student interaction (teacher-student talk) to address a specific learning goal. Similarly students' alternative conceptions on a topic from the literature and the pedagogical approach intended to be utilised in the teaching can be developed at both large and fine grain size, and both features are important in order to address the specific teaching aims in the designed teaching.

SUBJECT AND SAMPLE SIZE
A case study encompassing two classes was conducted in one school in Penang: an experimental class (37 students) who followed the designed teaching sequence and a baseline class (27 students) who served as a comparison group and followed a similar curriculum and normal classroom teaching. The school was not chosen from a random sample because it was selected based on having more than one class science and the students have similar academic ability. This is to ensure that the findings from this study were solely based on the differences in the teaching materials used.

Also, eight classes in eight different schools (189 students) who served as convenience samples and reference groups were selected in order to compare the differences on their conceptual understanding of aspects of electrochemistry in a wider sample. Similar post diagnostic test papers were given to the students after they had been taught electrochemistry. The results from the students' responses were later compared with those from the experimental and baseline classes.

DATA COLLECTION METHODS
The data collected in this study was mainly focused on the responses in the post diagnostic test. The recorded teaching for each lesson in the experimental class was the second main data in this study and was used in order to analyse the sequencing of the content in the actual teaching. This data was later compared with the contents of the designed teaching. Finally, the interview data from the students and the teacher were gathered and treated as additional research data in order to support the findings from the post diagnostic test and the teaching analysis regarding the students' and teacher's perceptions of the teaching. In this paper, only the data in one of the items in the post diagnostic test are presented.

DATA ANALYSIS
The analysis in this study starts by using the ideographic approach, followed by the nomothetic approach. After the ideographic analysis of the students' responses, the following coding schemes are applied as a means to analyse students' responses using the nomothetic approach (Driver & Erickson, 1983).
For example, one of the students' responses:
'There is a flow of electricity in the wire' (Student a)

This response shows that 'Student a' understood that there is a flow of electricity in the wire that makes it possible to light up the bulb, but the response does not contain the taught key features; that is, 'this is because electrons move in the wire from the anode to the cathode'. Thus, this response is analysed ideographically. However, as this response is coded as 'partially correct', this is a nomothetic analysis. There are four types of categories (set) are developed, which are 'Scientifically correct (SC), Partially correct (PC), Other (O)' and 'Not attempted (NA)'. The students' responses were analysed using percentages for the convenience samples and using Chi-square test of independence for the baseline and experimental classes. The results from the experimental and baseline class are compared using a Chi-square test of independence while the results in other eight schools (convenience samples) are presented in the form of percentages as the values are not compared in terms of significant difference but just to determine the numbers of 'scientifically correct' and other categories.

RESULTS AND DISCUSSIONS

Table 1 shows the results for the experimental and baseline classes on one of the learning areas under investigation which is aimed to investigate students' conceptual understanding about the nature and properties of electrolytes and electrons that influence the conductivity in the electrolytic cell. The five items in the question 1 relate to electrolyte having negative (anion) and positive (cation) ions, and only being able to conduct electricity when they are in an aqueous (1a) or molten state (1c) whilst not being able to do so when in a solid state (1b). Furthermore, the students' understanding of the properties of non-electrolytes (e.g. properties of covalent compound) is also investigated (1d). Finally, the students were required to define an electrolyte in the last question (1e).

Table 1 below shows that there were significant differences in the number of correct responses between the experimental and baseline groups relating to the nature and properties of electrolytes for items 1a, 1b, 1c and 1e, meaning that more students in the experimental class were able to answer correctly compared to the baseline class. Even though there was no significant difference for item 1d, it still shows that about 18% more students in the experimental class performed better than the baseline class.

Table 1: Chi-square results for the 'scientifically correct' answers in question 1

Question	Exp		Bl		Chi-square (χ^2)	Probability (ρ)	Fisher exact test	Chi-square critical (χ^2)	α (critical)
	SC	%	SC	%					
1a	26	70.3	8	29.6	10.35	0.001	0.002	6.64	0.01
1b	30	81.1	6	22.2	21.97	0.000	0.000	10.83	0.001
1c	29	78.4	5	18.5	22.46	0.000	0.000	10.83	0.001
1d	19	51.4	9	33.3	2.06	0.151	0.204	3.84	0.05
1e	15	40.5	4	14.8	4.95	0.026	0.030	3.84	0.05

The results for the eight different schools after they had been taught the topic are shown in Table 2 below. For item 1a presented in Table 2, it can be seen that none of the classes were able to achieve more than 50% 'scientifically correct' answers. The results illustrate that the students' performances were very weak and clearly show that they were having difficulties explaining the properties of electrolytes that makes them able to light up the bulb when in an aqueous state. For the rest of the items in Table 2, it can be seen that only one class (Class G) was able to achieve 80% 'scientifically correct' answers for item 1e which asks students the definition of 'electrolyte'.

The findings show that students who were from the baseline class and followed the normal classroom teaching were mainly weak in answering the 'scientifically correct' (SC) answers. They showed lack of understanding regarding the roles of ions and electrons in the solution and external wire respectively.

Table 2: Results of the 'scientifically correct' (SC) answers for item 1 in eight schools

Class/Items (%)	1a	1b	1c	1d	1e
A	35.1%	35.1%	29.7%	56.8%	18.9%
B	27.6%	37.9%	24.1%	17.2%	3.4%
C	18.5%	14.8%	14.8%	22.2%	7.4%
D	30.4%	39.1%	39.1%	43.5%	8.7%
E	18.2%	18.2%	18.2%	40.9%	27.3%
F	22.7%	27.3%	22.7%	18.2%	0.0%
G	6.7%	6.7%	46.7%	13.3%	80.0%
H	21.4%	7.1%	28.6%	35.7%	28.6%

However, other results show in Table 2 above for the convinience samples show that most of the students' performances were rather weak in all the items in question 1 except for item 1e in Class G.

Following the above discussions, students' difficulties were divided into two main areas:
1. Not able to generate detailed explanations of the chemical event.
2. Not able to relate the macroscopic, sub-microscopic and symbolic entities, or to relate any of the two entities.

It is observed that most of the 'scientifically correct' responses were very short and simple but they were accepted as 'scientifically correct' because students may have difficulty generating detailed explanations in *English* as it is not their first language; thus, it is not expected that the most of the responses provided by the students would contain detailed descriptions of the chemical event. However, there were responses that showed some students were able to provide good scientific knowledge, even though the numbers were small. Below are two responses from students in Class A for item 1a.

> 'There are freely moving ions' [Student X]
> 'Aqueous X contains free-moving ions' [Student Y]

In comparison to the experimental class, the explanation was more specific and details of the chemical process were illustrated clearly as shown below:

> 'I think the aqueous allows the bulb to light up because the ions that is anion and cation move to anode and cathode respectively. This will cause freely moving electrons in the circuit and will produce electric current' [Student R]
> 'In aqueous X, there is freely moving ions of substance X. The freely moving ions allow the electricity to flow. Therefore, the circuit is complete. So, the bulb will lights up' [Student S]

Furthermore, in the baseline class and the convenience samples, there were responses which showed some spelling and grammatical errors, but as long as the responses were understandable, they were coded according to the coding schemes mentioned earlier. Also from the responses, some students did not demonstrate confidence writing their answers, probably because it is in *English*. In addition, there were many students who did not attempt the questions, which might be because they found the questions difficult; and it was also possible that they may not take the questions seriously because the test was not an examination paper.

Also, most of the responses in the baseline class and the convenience samples did not demonstrate many misconceptions   because most of the responses indicate that students experienced difficulties in generating explanations from the taught content; for example, explaining the concepts, the terms, and the chemical changes and reactions that occur in the electrolytic cell. It is found that many students were unable to generate an explanation about the chemical event based on factual recall. Thus, the main difficulties that are faced by the students are not about developing misconceptions after they have been taught the topic; but rather the difficulties lie more with generating detailed explanations regarding the chemical event.

Following the above results on students' ideas about ions and electrons in the electrolytic cell, students were found to have difficulties relating the three entities, which are: macroscopic, sub-microscopic and symbolic. In some cases (not always), there are only two entities involved; for example, macroscopic observation is explained by using the sub-microscopic entities, and sometimes it is not necessary to present the symbolic entities, or the sub-microscopic entities with symbolic entities.

CONCLUSIONS
The data presented from the chi-square analysis were able to show the differences between the experimental and baseline students' performance in item 1. There were differences in their conceptual understanding especially when the students provided descriptive explanations that require further elaboration. The students in the experimental class provided better structured and more precise answers, showing that they had better scientific understanding and were more confident in writing their responses than the baseline class, whose answers are shorter and lack some taught key features of the scientific explanation. The analyses echo those students in the baseline class who were unable to generate detailed factual explanations in their responses, similar to those of eight classes (convenience samples). Consequently, this study has provided evidence that students in the experimental class were able to generate more detailed explanations in their responses.

Furthermore, the students in the experimental class appeared able to relate their macroscopic observation to sub-microscopic entities (or two entities) from their written responses compared to the baseline class (this is also observed in the reference group). For example, almost more than 50% (even higher) of students in the experimental class were able to relate the presence of the freely moving ions in the electrolyte (sub-microscopic) with the bulb lighting up (macroscopic). In another instance, the students were able to relate the bulb lighting up with the movements of electrons. From the findings obtained from the analysis of the results, the evidence shows that students in the experimental class developed a better conceptual understanding following teaching, in comparison to the baseline class and the convenience samples. Thus, there must be some aspects of the designed teaching sequence that contribute to these differences in the achievement of these classes.

The eight classes that were chosen as convenience samples (reference groups) reflect typical schools in Malaysia who followed normal classroom teaching with the same content as stated in the chemistry syllabus. The findings in this study have provided some empirical evidence that many students developed conceptual difficulties in this learning area and the results do not support any assumption that normal classroom teaching has provided essential support for students to generate detailed, factual explanations about the chemical event (phenomena). This shows that this is a serious matter to be tackled in the classroom teaching and learning regarding a specific, difficult area in chemistry. Also, the findings suggest that the typical classroom teaching and learning may be unsuitable for improving students' conceptual understanding in relating the three levels of representation in learning chemistry when connecting the macroscopic, sub-microscopic and symbolic entities. Drawing from this, the effectiveness of the designed teaching sequence can be determined according to whether or not students in the experimental class had developed a better conceptual understanding after teaching in comparison to the baseline class and the reference group in this study.

In conclusion, as mentioned at the end of the discussions regarding the roles of ions and electrons in the conductivity of the electrolytic cell, some aspects of the designed teaching sequence may have achieved the particular teaching and learning aims, but other aspects may not be as successful. However, the designed teaching sequence has a promising potential to be used as a tool in the Malaysian classroom in order to improve students' conceptual scientific understanding of a particular aspect in electrochemistry.

REFERENCES

1. Acar, B., & Tarhan, L. (2007). Effect of cooperative learning strategies on students' understanding of concepts in electrochemistry. *International Journal of Science and Mathematics Education*, *5*: 349-373.
2. Ahtee, M., Asunta, T., & Palm, H. (2002). Student teachers' problem in teaching 'electrolysis' with a key demonstration. *Chemistry Education: Research and Practice in Europe*, *3*(3): 317-327.
3. Boulabiar, A., Bouraoui, K., Chastrette, M., & Abderrabba, M. (2004). A historical analysis of the Daniell cell and electrochemistry teaching in French and Tunisian textbooks. *Journal of Chemical Education*, *81*(5), 754-757.
4. Brant, L., Elen, J., H, J., Heerman, L., Couwenberg, I., Volckaert, L., & Morisse, H. (2001). *International Journal of Science Education*, *23*(12), 1303-1313.
5. Chou, C.Y. (2002). Science teacher's understanding of concepts in chemistry. *Proc. Natl. Sci. Counc. ROC(D), 12*(2), 73-78.
6. Driver, R., & Erickson, G. (1983). Theories-in-action: Some theoretical and empirical issues in the study of students' conceptual frameworks in science. *Studies in Science Education*, *10*, 37-60.
7. Eilks, I., Witteck, T., & Pietzner, V. (2009). A critical discussion of the efficacy of using visual learning aids from the internet to promote understanding, illustrated with examples explaining the Daniell voltaic cell. Eurasia Journal of Mathmatics, *Science & Technology Education*, *5*(2), 145-152.
8. Garnett, P. J. & Treagust, D. F. (1992a). Conceptual difficulties experienced by senior high school students of electrochemistry: Electric circuits and oxidation-reduction equations. *Journal of Research in Science Teaching*, *29*(2): 121-142.
9. Garnett, P. J., & Treagust, D. F. (1992b). Conceptual difficulties experienced by senior high school students of electrochemistry: Electrochemical (galvanic) and electrolytic cells. *Journal of Research in Science Teaching*, *29*(2): 1079-1099.
10. Garnett, P. J., Garnett, P. J. & Treagust, David, F. (1990). Implications of research on students' understanding of electrochemistry for improving science curricula and classroom practise. *International Journal of Science Education*, *12*(2), 147-156.
11. Greenbowe, T.J. (1994). An interactive multimedia software program for exploring electrochemical cells. *Journal of Chemical Education, 71*(7), 555-557.
12. Huddle, P. A., White, M. D., & Rogers, F. (2000). Using a teaching Model to correct known misconceptions in electrochemistry. *Journal of Chemical Education, 77*(1), 104-110.
13. Leach, J., & Scott, P. (2002). Designing and evaluating science teaching sequences: an approach drawing upon the concept of learning demand and a social constructivist perspective on learning. *Studies in Science Education, 38*, 115-142.

14. Leach, J., & Scott, P. (2008). Teaching for conceptual understanding: an approach drawing on individual and sociocultural perspectives. In S. Vosniadou (Ed.): *International handbook of research on conceptual change*. London: Routledge, pp. 647-675.
15. Millar, R., Leach, J., Osborne, J., & Ratcliffe. (2006). Improving practice in subject teaching: the contribution of research. In R. Millar, J. Leach, and M. Ratcliffe (Eds.). *Improving Subject Teaching: Lessons from research in science education* (London: Taylor and Francis), 60-78.
16. Morikawa, T., & Williamson, B.E. (2001). Model for teaching about electrical neutrality in electrolyte solutions. *Journal of Chemical Education*. 78(7), 934-936.
17. Niaz, M. (2002). Facilitating conceptual change in students' understanding of electrochemistry. *International Journal of Science Education*, *24*(4), 425-439.
18. Niaz, M., & Chacon, E. (2003). A conceptual change teaching strategy to facilitate high school students' understanding of electrochemistry. *Journal of Science Education and Technology*, *12*(2): 129-134.
19. Ogude, A.N., & Bradley, J.D. (1994). Ionic conduction and electrical neutrality in operating electrochemical cells. *Journal of Chemical Education, 71*(1), 29-34.
20. Ogude, A.N., & Bradley, J.D. (1996). Electrode processes and aspects relating to cell emf, current, and cell components in operating electrochemical cells. *Journal of Chemical Education, 73*(12), 1145-1149.
21. Özkaya, A. R. (2002). Conceptual difficulties experienced by prospective teachers in electrochemistry: half-cell potential, cell potential, and chemical and electrochemical equilibrium in galvanic cells. *Journal of Chemical Education*, *79*(6), 735-738.
22. Özkaya, A. R., Uce, M., Saricayir, H., & Sahin, M. (2006). Effectiveness of a conceptual change-oriented teaching strategy to improve students' understanding of galvanic cells. *Journal of Chemical Education, 83*(11): 1719-1723.
23. Özmen, H. (2004). Some students misconceptions in chemistry: A literature review of chemical bonding. *Journal of Science Education and Technology, 13*(2), 147-159.
24. Sanger, M. J., & Greenbowe, T. J. (1997a). Students' misconceptions in electrochemistry: current flow in electrolyte solutions and the salt bridge. *Journal of Chemical Education*, *74*(7): 819-823.
25. Sanger, M. J., & Greenbowe, T. J. (1997b). Common student misconceptions in electrochemistry: Galvanic, electrolytic and concentration cells. *Journal of Research in Science Teaching, 34*(4): 377-398.
26. Sanger, M. J., & Greenbowe, T. J. (1999). An analysis of college chemistry textbooks as sources of misconceptions and errors in electrochemistry. *Journal of Chemical Education*, *76*(6): 853-860.
27. Sanger, M. J., & Greenbowe, T.J. (2000). Addressing student misconceptions concerning electron flow in aqueous solutions with instruction including computer animations and conceptual change strategies. *International Journal of Science Education, 22* (5): 521-537.
28. Schmidt, H-J., & Volke, D. (2003). Shift of meaning and students' alternative concepts. Research Report. *International Journal of Science Education*, *25*(11): 1409-1424.
29. Schmidt, H-J., Marohn, A., & Harrison, A. G. (2007). Factors that prevent learning in electrochemistry. *Journal of Research in Science Teaching*, *44*(2), 258-283.
30. Thompson, J., & Soyibo, K. (2002). Effects of lecture, teacher demonstrations, discussions and practical work on 10th graders' attitudes to chemistry and understanding of electrolysis. *Research in Science & Technological Education, 20*, 25-34.
31. Treagust, D.F., Chittleborough, G., & Mamiala, T.L. (2003). The role of submicroscopic and symbolic representations in chemical explanations. *International Journal of Science Education*, *25*(11), 1353-1368.