Table 6 Students in good-, alternative-, and misconception categories

Topics (number of items)	Pre-test categories (%) Good-	Alternative-	Mis-	Post-test categories (%) Good-	Alternative-	Mis-
1. Definition and calculation (10)	9.66	32.96	57.39	81.44	9.84	8.71
2. Theories (14)	10.06	26.95	62.99	54.87	31.49	13.64
3. Nature of substances (4)	20.45	4.55	75.00	60.23	37.50	2.27
4. Surface area (8)	1.14	51.70	47.16	56.25	24.43	19.32
5. Concentration (8)	18.75	48.86	32.39	69.89	23.86	6.25
6. Catalyst and retarder (8)	22.73	55.68	21.59	54.55	27.27	18.18
7. Temperature (8)	17.05	53.98	28.98	59.09	32.95	7.95
Total (30)	13.69	38.45	47.86	64.72	24.65	10.63

Percentages of students in the good-, alternative-, and misconception categories

Prior to the implementation of inquiry incorporated with analogy learning plans on chemical reaction rate, the percentages of students in the good-, alternative-, and misconception categories of the pre-conceptual test were 13.69, 38.45, and 47.86, respectively (Table 6). They were mostly in the alternative- and misconceptions (86.31). Most of the students were in the misconception category for the topics of the effect of the nature of substances (75.00), theories (62.99), and definition and calculation (57.39).

Right after the implementation, the percentages of students in these categories were 64.72, 24.65, and 10.63, respectively. Most students (more than 50%) were in the categories of good-conception for all of the topics. The highest percentage of students with good conceptions was in the topic of definition and calculation (81.44). However, some students (35.28%) were still classified in the alternative- and good-conceptions, especially in the topics of the effect of catalyst and retarder (45.45%), the theories of chemical reaction rate (45.13%), and the effect of surface area (43.75%). Since the percentages of students in the good conception category increased and the percentages in the alternative- and misconception categories decreased, it appears that this implementation was successful in enhancing students' conceptual understanding of chemical reaction rate.

Since the corresponding inquiry learning activities deeply engaged and challenged students in all of the steps of the activity process, their conceptual understanding was enhanced (Green *et al.*, 2004). Therefore, the instructors were no longer the main source of knowledge about activities, but were the facilitators who guided their students through the inquiry process (Deters, 2005). In addition, the analogy activities were often enjoyable and interesting for students as some students commented that they favour analogies with social relevance (Sarantopoulos and Tsaparlis, 2004) and familiar analogies from science textbooks (Eskandar *et al.*, 2013). Analogies can engage students' interest and make it possible for them to understand difficult and intangible concepts (Harrison and Coll, 2007).

Students' analogies of chemical reaction rate

Students analogies generated during each topic of chemical reaction rate were also investigated, as shown in Table 7. These analogies contain student conceptions which may be correct (good-conceptions), partially correct but incomplete (alternative-conceptions), or simply wrong (misconception) when compared to scientific consensus about the concepts (Mulford and Robinson, 2002). However, even partially correct analogies can be powerful tools to help students to understand, visualize, and recall what they have learned in class (Orgill and Bodner, 2004).

Since there might not have been analogies which perfectly matched the target concepts, the information expressed in the generated analogies may not have been powerful enough to really identify their conceptions. However, the authors attempted to categorize their conceptions into correct (✔), partially correct or alternative- (✔/✘), or misconception (✘) to promote group discussion to be more powerful at promoting student conceptual changes (Çalik *et al.*, 2010; Davis, 2013). Examples of student identification of similarities and differences in their generated analogies are shown in Table 8.

For example, some students gave a correct analogy (✔) about boiling small and large sized starch bubbles for the effect of surface area on chemical reaction. One of the similarities of the target and analogue is that small sized and large sized starch bubbles represent large and small surface areas, respectively. Some students gave a partially correct analogy (✔/✘), which is dissolving a curry cube and powder in water. One of the differences in this case is that sugar dissolving in water is not a chemical change, but a physical change. In another example, some students gave a correct analogy (✔) about making fire balls with different amounts of gunpowder for the effect of concentration on chemical reaction. One of the similarities of the target and analogue is that the amount of gunpowder represents the concentration of gunpowder in the fire ball mixture. Some students gave a partially correct analogy (✔/✘), which is fishing for catfish in natural and farm ponds. One of the differences in this case is that it cannot be confirmed that the amount of catfish in the farm-pond is equal to the amount in the natural-pond.

Conclusion, implications and limitations

Despite the limitations of this study that involved students from a single school, this study verified that the implementation of inquiry supported by analogy learning activities was an effective means of enhancing and retaining students' conceptual understanding of chemical reaction rate. The normalized learning gain

Table 7 Examples of analogies of reaction rate generated by students[a]

Topics	Students' analogies (analogue = A, target concept = T)
1. Definition and calculation	1. Driving a car at different speeds, but an equal distance. 2. Peeling palm fruits at different speeds, but equal time. 3. Marathon runners running at different speeds, but over an equal distance. ✓ A: speed of driving, peeling, or running, T: reaction rate ✓ A: driving, peeling, or running time, T: reaction time
2. Theories	1. Driving a car uphill. 2. Riding a bicycle uphill. ✓ A: slope of hill, T: amount of activation energy (E_a) ✗ A: time for driving or riding uphill, T: reaction time 3. Riding a surfboard over different heights of waves. ✓ A: heights of waves, T: amount of activation energy (E_a) ✗ A: time for driving or riding uphill, T: reaction time (partly about staying or standing still on a surfboard)
3. Nature of substances	1. Drying hair with a fan and an electronic dryer. ✓ A: a fan and an electronic dryer, T: nature of reactants ✓ A: time for hair drying, T: reaction time 2. Riding a motorcycle and biking a bicycle. ✓ A: motorcycle and biking a bicycle, T: nature of reactants ✓ A: time for riding or biking to stop point, T: reaction time 3. Running with running shoes and slippers. ✓ A: running shoes and slippers, T: nature of reactants ✓ A: time used for running to stop point, T: reaction time
4. Surface area	1. Baking small and large sized cupcakes. ✓ A: large and small cupcakes, T: small and large surface area ✓ A: raw and baked cupcake, T: reactants and products ✓ A: cooking time, T: reaction time 2. Dissolving curry cube and powder in water. ✓ A: curry cube and powder, T: small and large surface area ✗ A: curry solution (physical change), T: reaction product ✓ A: dissolving time, T: reaction time 3. Boiling small and large sizes of starch bubbles. ✓ A: large and small bubbles, T: small and large surface area ✓ A: boiling time, T: reaction time ✓ A: cooked starch bubbles, T: reaction product
5. Concentration	1. Making fire balls with different amount of gunpowder. ✓ A: amount of gunpowder, T: concentration of reactant ✗ A: power of fire balls, T: reaction rate 2. Fishing catfish in the natural and farm ponds. ✓ A: amount of catfish, T: concentration of reactant ✗ A: natural and farm ponds, T: high and low concentrations (partly about nature of substances) 3. Feeding a bird and a flock of birds with same amount of rice. ✓ A: amount of birds, T: concentration of reactant ✓ A: time used for bird-feeding, T: reaction time
6. Catalyst and retarder	1. Riding geared and non-geared bicycles over the same distance. ✓/✗ A: geared and non-geared bicycles, T: catalysed and non-catalysed reactions (partly about nature of substance) ✓ A: time for riding bike to stop point, T: reaction time 2. Driving a car on paved and unpaved roads. ✓/✗ A: paved and unpaved roads, T: catalysed and non-catalysed reactions (partly about nature of substance) ✓ A: time for driving to stop point, T: reaction time 3. Walking home with and without a shortcut. ✓ A: shortcut route, T: catalysed reaction ✓ A: time used for walking, T: reaction time
7. Temperature	1. Cooking rice at high and low temperatures. 2. Boiling eggs at high and low temperatures. 3. Baking rice popcorn at high and low temperatures. ✓ A: temperature used for cooking rice, boiling eggs, or baking rice popcorn, T: reaction temperature ✓ A: cooking, boiling, or baking time, T: reaction time ✓ A: cooked rice, eggs, or rice popcorn, T: reaction product

[a] Note: ✓, ✓/✗, and ✗ indicate the analogies that are correct, partially correct but incomplete, and simply wrong, respectively, when compared to the targets.

Table 8 Examples of student identification of similarities and differences in their generated analogies

Analogy	Analogue	Target
1. Definition of reaction rate: driving a car at different speeds, but over an equal distance.		
Similarities	– Speed of driving	– Reaction rate
	– Driving time	– Reaction time
Differences	– Physical change (no product)	– Chemical change (product generated)
	– People may feel tired	– Reactants have no feelings
2. Theories of reaction rate: riding a bicycle uphill.		
Similarities	– Slope of hill	– Amount of E_a
	– Time for riding	– Reaction time
	– Power used for riding	– Reaction energy
Differences	– Slope of a hill remains the same	– Amount of E_a can be decreased or increased
	– Physical change	– Chemical change
	– People may feel tired	– Reactants have no feelings
3. Nature of substances: riding a motorcycle and riding a bicycle.		
Similarities	– A motorcycle and a bicycle	– Nature of reactants
	– Time for riding	– Reaction time
Differences	– Physical change	– Chemical change
	– Fuel (chemical) for riding and energy for biking	– Reaction energy
4. Boiling small and large sized starch bubbles.		
Similarities	– Large bubbles	– Small surface areas
	– Boiling time	– Reaction time
	– Cooked starch bubbles	– Reaction products
Differences	– Sticky cooked bubbles often stick together	– Reaction products may not stick together
	– Eatable food	– Uneatable
5. Effect of concentration: making fire balls with different amounts of gunpowder.		
Similarities	– Amount of gunpowder	– Concentration of reactant
	– Power of fire balls	– Reaction rate
Differences	– Increasing gunpowder may not increase the power of the fire balls (improper mixing ingredients)	– Increasing the concentration always increases the rate
	– Fire ball explosion is an exothermic process	– A reaction may be an exothermic or an endothermic process
6. Effect of catalyst and retarder: driving a car on paved and unpaved roads.		
Similarities	– Paved and unpaved	– Catalysed and non-catalysed
	– Time for driving	– Reaction time
Differences	– Slope of road is not considered	– Amount of E_a involved
	– Physical change (no product)	– Chemical change
	– Unreliable of paved and unpaved roads in rural districts	– Catalyzed-always faster than non-catalyzed reactions
7. Effect of temperature: boiling eggs at high and low temperatures.		
Similarities	– Temperature for boiling	– Reaction temperature
	– Boiling time	– Reaction time
	– Cooked eggs	– Reaction product
	– Different types of eggs	– Different reactants
Differences	– Boiling eggs is an endothermic process, and the evaporation of water is an exothermic process	– A reaction may be an exothermic or an endothermic process

from pre- to post-conceptual tests showed a medium gain in understanding. The dependent samples t-test analysis indicated that the post-conceptual test score was statistically higher than the pre-test score, but was statistically lower than the retention test score at the significance level of 0.05. Prior to the implementation, students were mostly in the alternative- and misconception categories. After the implementation of the corresponding inquiry incorporated with analogy learning activities, the majority of the students moved to the good-conception categories. However, some students still held alternative- and misconceptions, which were expressed when they were asked to create their own analogy and to identify similarities and differences between their analogies and the targets for each chemical reaction rate topic.

This study may have implications for chemistry instructors, because inquiry activities may be an effective means of enhancing and retaining students' conceptual understanding, but may not be effective for helping them recognize their alternative- or misconceptions. The implementation of inquiry activities in conjunction with the corresponding analogies may be a more effective means of helping learners correct their alternative conceptions. It is advisable that instructors should design tasks or assignments to find out their students' understanding of reaction rate (Cunningham, 2007) and various cooperative learning methods (classroom discussion, argumentation, or negotiation) can enable better understanding of the concepts of reaction rate and improve students' motivation to study chemistry (Venville, 2008; Kırıka and Bozb, 2012). These learning methods could truly enhance and retain students' understanding of reaction rate. The instructors should keep in mind that while many analogies are useful and do convey useful information, the message of the analogies is not always obvious to all students. They may misinterpret the main points of the analogies which can lead students to have alternative conceptions (Orgill and Bodner, 2004). Therefore, instructors have to be assured that the students understand the scientific concepts, and do not develop alternative conceptions from the analogy (Venville, 2008). Analogy instruction can inform teachers how analogies can be used effectively in classrooms. It is advisable that providing teachers opportunities to practice and experience teaching with analogies will enhance the successful enhancement of students' conceptual understanding in their classes (Harrison and Coll, 2007; Venville, 2008).

The retention test score obtained in this study was higher than the post-test score. This limitation arose because after the implementation and post-conceptual test on chemical reaction rate, the participants had access to additional instruction and did additional homework before the retention test. In addition, they were studying the topic of chemical equilibrium which relates to the topic of chemical reaction rate, before the retention test. To avoid this limitation, the retention test should be completed before the participants begin to study the next topics which may relate to the topic being studied. The other limitation is that the instructor did not spent enough time organising a group discussion between the students having similar and different conceptions. Instructors should enable students to recognise when they have unacceptable conceptions and should help them to correct their understanding (Chandrasegaran *et al.*, 2007).

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Small-Scale Inquiry-Based Experiments to Enhance High School Students' Conceptual Understanding of Electrochemistry

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Abstract. This study aimed to develop small-scale experiments of electrochemistry based on inquiry learning approach and to use the experiments to enhance students' conceptual understanding of electrochemistry especially at the molecular level. The experiments consisted of oxidation and reduction reactions, galvanic cells, cathodic protection, and batteries. The data collecting tools included 24 items of two-tier conceptual test and mental model drawings of a galvanic cell. Thirty-one Grade-12 students participated in the study. The paired samples T-test analysis revealed that the average post-experiment score (mean 30.68, SD 10.86) of conceptual test was statistically higher than the average pre-experiment score (mean 20.81, SD 10.95) at 0.05 level of significance. In addition, the average post-experiment score (mean 12.10, SD 5.49) of mental models was statistically higher than the average pre-experiment score (mean 7.69, SD 5.47) at 0.05 level of significance. Prior to performing the experiments, most students were in the *Partial Understanding with Specific Misunderstanding* (PU+MU) to *No Understanding* (NU) categories. After performing the experiments, the students' major categories moved to the more correct scientific conceptions, the *Partial Understanding* (PU) to *Partial Understanding with Specific Misunderstanding* (PU+MU). This indicated that the experiments can enhance students' conceptual understanding and mental models of electrochemistry.

Keywords: electrochemistry, small-scale experiment, molecular conceptual understanding.

1. Introduction

Almost all high school students are required to study electrochemistry in both lecture and laboratory settings. Many students revealed that electrochemistry is one of the difficult chemistry topics. In addition, some students may hold alternative conceptions – conceptions that are not consistent with the consensus of scientific community, which may be partially right, but incomplete, or just simply wrong [1] – about the electrochemistry. Requiring students to draw and explain molecular representations of the some electrochemistry experiments, such as reaction in galvanic cells may to reveal their understandings and identify some of their alternative conceptions.

1.1. Roles of mental models in learning chemistry

Mental models are representations of objects, ideas, thinking, or processes which individuals intrinsically construct during cognitive functioning [2], [3]. People use these models to reason, describe, explain, and/or predict scientific phenomena (processes or systems). Mental models can be generated in various formats to communicate ideas to other people or to solve problems [2], [3], and can represent either physical entities via verbal descriptions, diagrams, simulations, and concrete models, or conceptual understanding, such as models of ideas, thinking, or intangible concepts [4]. If their mental model fails to assimilate new

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experiences, students may modify their existing models or generate alternative models [5]. Mental models are considered as an important part of learners' conceptual frameworks [5] and they play a potential role in learning chemistry at the molecular level, because much of chemistry involved at this level and cannot access to direct perception [6]. Full understanding of chemical processes involves the ability to connect events at a macroscopic level with events at the molecular level [7]. Therefore, students need to transform these invisible events or phenomena into equivalent mental (or conceptual) models or representations which is difficult for many students [8],[9],[10].

1.2. Three levels of representations in chemistry

Representations in chemistry, also called chemical representations, refer to various types of formulas, structures, and symbols used to represent chemical processes and conceptual entities, such molecules and atoms. They can be viewed as metaphors, models, and theoretical constructs of chemists' interpretation of nature and reality [11]. Previous research highlighted three levels of representations in chemistry as follows [7],[12].

1) Macroscopic representation. This describes bulk properties of tangible and visible phenomena in the everyday experiences of learners when observing changes in the properties of matter, such as color changes, formation of gases, and precipitates in chemical reactions.

2) Microscopic Representation. This is also called sub-microscopic or molecular representation, provides explanations at the particulate level in which matter is composed of atoms, molecules and ions.

3) Symbolic Representation. This involves the use of chemical symbols, formulas, and equations, as well as molecular structure drawings, diagrams, and models to symbolize matter. It can provide information for both macroscopic (relative amounts or moles of involved substances) and molecular levels (numbers of formula unit of involved substances).

Students' conceptual understandings of electrochemistry can be investigated by using conceptual test and by drawing mental models of electrochemistry. The information about students' conceptual understanding before and after performing experiments and learning in lecture classes can be used in the design of animations with molecular features to best support students' acquisition in learning electrochemistry especially what happens at the molecular level.

2. Research Purpose and Objectives

The primary purpose of this study was to explore students' conceptual understanding of electrochemistry by using conceptual test and mental model drawings prior to and after performing corresponding experiments. The research objectives were:

1) To compare students' conceptual understanding scores before and after they performed corresponding experiments when assessed by the conceptual test and mental model drawing of electrochemistry.

2) To categorize students' conceptual understanding regarding their explanations in the conceptual test and their mental models of electrochemistry before and after they performed corresponding experiments.

3. Methodology

This one-group pre-test post-test study used a "mixed methods" design [13] that incorporated both qualitative and quantitative methods as its research paradigm.

3.1. Participants

With permission from the course instructors, 31 Grade-12 students in the Gifted in Science classroom at Satrisiriket School in Srisaket Province in the first semester of academic year 2014 participated in this study.

3.2. Research tools

Two types of research tools were used in this study, treatment and data collection tools. The treatment tools consisted of four small-scale experiments based on the inquiry learning approach, oxidation and reduction reactions, galvanic cells, cathodic protection, and connecting batteries in series. The two data collecting tools were a conceptual test of electrochemistry containing 24 items of two-tier three-choice test in which students were required to make their choices of answers in the first tier, and then provide their explanations for those choices, and mental model drawings of galvanic cells in which students were asked to draw their understandings of what happens at a molecular or particulate level in provided galvanic cells ($Zn|Zn^{2+}||Cu|Cu^{2+}$, $Zn|Zn^{2+}||Ni|Ni^{2+}$, or $Ni|Ni^{2+}||Cu|Cu^{2+}$) as shown in Fig. 1.

3.3. Implementation

The participants were requested to complete conceptual test of electrochemistry and mental model drawings of galvanic cells before participating in (four small-scale experiments of electrochemistry over a period of nine hours (three hours a week). After this period, they were asked to complete a conceptual test of electrochemistry and mental model drawings again.

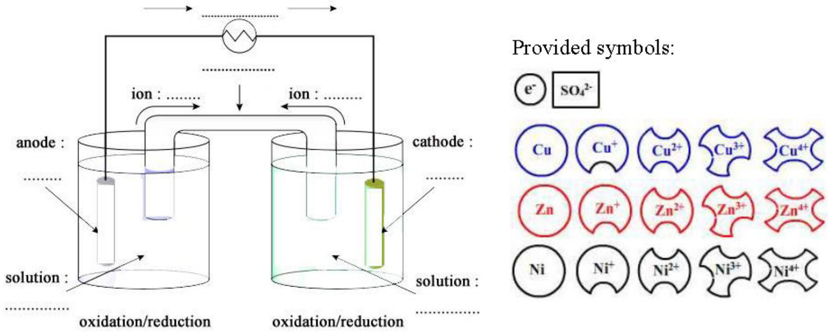

Fig. 1: Mental model drawing for a given galvanic cell ($Zn|Zn^{2+}||Cu|Cu^{2+}$, $Zn|Zn^{2+}||Ni|Ni^{2+}$, or $Ni|Ni^{2+}||Cu|Cu^{2+}$).

3.4. Data analysis

The data collected in this study were analyzed as follows:

1) Conceptual tests: The pre- and post-conceptual test answers were awarded 1 and 0 point for correct and incorrect choices respectively in the first tier. The explanations provided in the second tier were awarded 0, 0.25, 0.5, 0.75, or 1 point for their conceptual understandings (possible total score for each item was 3 points). Students' explanations were categorized into five groups as follows [14]:

- Explanations with all concepts corresponding to both scientific consensus and scientific concepts of scientists scored 1 point and were defined as "Sound Understanding: SU".
- Explanations with at least one concept corresponding to scientific consensus and scientific concepts of scientists scored 0.75 point and were defined as "Partial Understanding: PU".
- Explanations with at least one concept corresponding to scientific consensus and scientific concepts of scientists but partially alternate to scientific concepts scored 0.5 point and were defined as "Partial Understanding with Specific Misunderstanding: PU+MU".
- Explanations with no concept corresponding to scientific consensus and scientific concepts of scientists scored 0.25 point and were defined as "Specific Misunderstanding: MU".
- Explanations with no detail or no scientific concepts scored 0 point and were defined as "No Understanding: NU".

2) Mental model drawings: The pre- and post-mental model drawings were scored by using a rubric developed by the authors. These models were also categorized into five groups in the same ways as the explanations in the conceptual tests. The available score was 18 points, 6 points for the macroscopic features and labelling and 12 points for the macroscopic features.

3) Students' scores from pre- and post-conceptual tests and mental model drawings were analysed by the use of paired-samples T-test.

4. Results and Discussion

There were two main sections of results in this study: 1) students' scores of conceptual test and mental model drawings of electrochemistry, and 2) conceptual categories of electrochemistry.

4.1. Students' scores in the conceptual tests and mental model drawings

There were two types of scores in this study, those for the conceptual tests and those for the mental model drawings.

Students' pre-conceptual test scores for the means of the first and second tiers and the totals were 12.29, 8.52, and 20.81, respectively (Table 1). After the completion of the four small-scale experiments, the means of the post-test scores were 16.35, 14.32, and 30.68, respectively. The gains in the conceptual scores were 4.06, 5.81, and 9.87 respectively. The paired-samples T-test analysis indicated that these differences between means of the pre- and post-conceptual tests were statistically significant in all cases. The percentage for the means of the pre-test scores for the first tier choices (51.21%) was much higher than that for the second tier explanation parts (35.48%). After the experiments, the percentage for the mean of the post-test score in the choice part (68.15%) was still higher than that for the second tier explanation part (59.68%). This situation arose because sometimes the students knew the answers without complete scientific conceptual explanation. As a result, they were able to provide partial-, alternative-, or misunderstandings for their answers [14]. These improvements in the percentages of the post-test scores indicated that these small-scale experiments of electrochemistry were effective in the enhancement of the students' conceptual understandings.

Table 1: Students' scores assessed by using conceptual test of electrochemistry and mental model drawings

Test	Test score										T-test	
	Avai-	Pre-test			Post-test			Change				
	lable	mean	SD	%	mean	SD	%	mean	SD	%	T	p
Conceptual test	**48**	**20.81**	**10.95**	**43.35**	**30.68**	**10.86**	**63.91**	**9.87**	**2.47**	**20.56**	**22.22**	**0.00***
Choice (1st tier)	24	12.29	4.47	51.21	16.35	4.30	68.15	4.06	1.82	16.94	12.40	0.00*
Explanation (2nd tier)	24	8.52	6.71	35.48	14.32	6.87	59.68	5.81	1.89	24.19	17.13	0.00*
Mental model drawings	**18**	**7.69**	**5.47**	**42.74**	**12.10**	**5.49**	**67.20**	**4.40**	**2.08**	**24.46**	**11.77**	**0.00***
Macroscopic feature	6	3.05	1.71	50.81	4.06	1.78	67.74	1.02	0.71	16.94	7.94	0.00*
Molecular feature	12	4.65	3.86	38.71	8.03	3.75	66.94	3.39	1.69	28.23	11.18	0.00*
Total	**66**	**28.50**	**16.33**	**43.18**	**42.77**	**16.15**	**64.81**	**14.27**	**3.53**	**21.63**	**22.79**	**0.00***

* Statistical differences when performed by paired-samples T-test at 0.05 level of significance.

For the mental model drawings of galvanic cells, the students' mean pre-drawing scores in macroscopic (and labeling) features, molecular (or microscopic) features, and totals were 3.05, 4.65, and 7.69 respectively and the mean post-drawing scores were 4.06, 8.03, and 12.10 respectively. The post-drawing gains in the mental model scores were 1.02, 3.39, and 4.40 respectively. The paired-samples T-test analysis indicated that these changes from pre- to post-drawings were statistically significant in all cases.

Students obtained a percentage for the pre-mental model score of 50.81% for macroscopic features, much higher than the 38.71% for molecular features. An explanation of this may be that students find molecular features difficult to understand due to their intangibility and/or invisibility [4]. However, after involvement in the experiments, the students' percentage increase in the mean post-mental model score regarding molecular features was 66.94%. This improvement of 28.23% compared to the 38.71% for the pre-test indicated that the small-scale experiments of electrochemistry were effective in the enhancement of the students' mental models at the molecular level. Although the students obtained mean post-test scores significantly higher than the mean pre-test scores for conceptual tests and mental model drawings, these gains were not as high as they should be.

4.2. Students' conceptual categories in regard of electrochemistry

The students were categorized into five groups regarding their explanations in the conceptual tests and information expressed in their mental model drawings. Prior to their involvement in the four small-scale experiments of electrochemistry, their explanations were categorized mostly in PU+MU (32.26%), MU (25.81%), and NU (25.81%) as shown in Table 2. After the experiments and as a result of their post-conceptual test explanations the students moved to the more correct conceptual understanding categories of

PU (29.03%), PU+MU (25.82%), and MU (22.58%). When asked to draw mental models of how they understand what happens at the molecular level in galvanic cells, the categorisation of the students' macroscopic information at the pre-stage fell mostly in PU (35.48%), MU (25.81%), and PU+MU (22.58%), and their molecular information for the same stage was categorized mostly in MU (29.03%), NU (25.81%), and PU (22.58%). After the experiments, their models moved to more correct conceptual understanding categories. For macroscopic information, most were in SU (32.26%), PU (29.03%), and PU+MU (19.35%), and for molecular information, most were categorised in SU (35.48%) and PU (22.58%).

Table 2: Frequencies and percentages of students in the five conceptual categories

Frequencies (f) and %		Pre-test					Post-test				
		SU	PU	PU+MU	MU	NU	SU	PU	PU+MU	MU	NU
Conceptual tests : Explanation part	f	1	4	10	8	8	6	9	8	7	1
	%	3.23	12.90	32.26	25.81	25.81	19.35	29.03	25.81	22.58	3.23
Mental models: Macroscopic feature	f	2	11	7	8	3	10	9	6	5	1
	%	6.45	35.48	22.58	25.81	9.68	32.26	29.03	19.35	16.13	3.23
Mental models: Molecular feature	f	2	7	5	9	8	11	7	6	6	1
	%	6.45	22.58	16.13	29.03	25.81	35.48	22.58	19.35	19.35	3.23

Most students provided more complete macroscopic information than molecular information at both the pre- and post-stages as the former is not difficult to understand due to images shown in learning materials and more obvious observations of changes in the experiments. The reason for the students' higher post-stage score may be due to the fact that after the experience of the experiments, the students obtained relevant information by observations of the experiments, leading to modification of their mental models to provide more reasonable explanations of what happens at the molecular level of given galvanic cells. However, some students' modified models may still contain misconceptions [1].

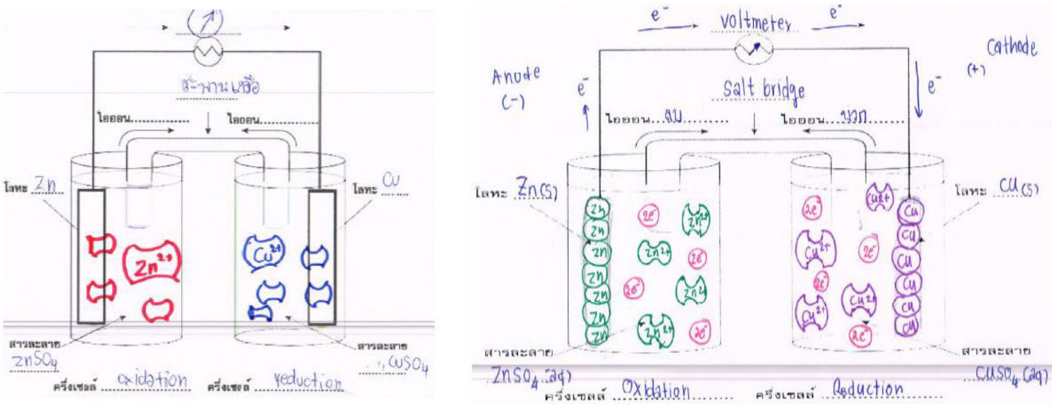

Fig. 2: Examples of students' pre- (left) and post-Mental model drawing (right) for a given galvanic cell.

5. Conclusion and Implications

The study results indicated that the small-scale experiments of electrochemistry based on inquiry learning approach was effective to enhance students' conceptual understanding and mental models of corresponding concepts. The students' obtained the post-conceptual test score statistically higher than the pre-test score. In addition, their post-mental model score was statistically higher than the pre-model score. The majorities of the pre-experiment scores were from the choice part of the conceptual test and from the macroscopic part of the mental models. However, after performing corresponding experiments, their post-experiment scores in the explanation part of the conceptual test and in the molecular part of the mental models played more important role than in the pre-experimental scores. Prior to performing corresponding experiments, the majority of students were in the partial understanding with specific misunderstanding

(PU+MU) to no understanding (NU) categories. After performing the experiments, the majority them moved to the partial understanding (PU) to partial understanding with specific misunderstanding (PU+MU) categories, which were better scientific conceptions. This indicated that the corresponding experiments can enhance students' conceptual understanding and mental models of electrochemistry.

This study may have implications for chemistry instructors in that teaching or directing students to perform an experiment might be not enough to help students understand important concepts at the molecular level. Chemistry instructors might consider using a simulation, animation, or other visualization tools to help students visualize concepts at the molecular level and then connect these concepts to the corresponding macroscopic procedure or features. As a result, students may achieve a complete and lasting conceptual understanding [10]. Students' mental models of a specific process contain rich relevant information that can be used in designing an animation or simulation to support students' acquisition or mental model [15].

6. Further Study

The information about students' conceptual understanding of electrochemistry and mental models of galvanic cells will be used in the design of a molecular animation to support students' understanding of electrochemistry. The small-scale experiments incorporated with corresponding molecular animation will be implemented to investigate how they impact students' conceptual understandings and mental models of electrochemistry. Alternative conceptions prior to and after the implementation will be indentified.

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