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Examining Senior High School Students' Ability in Constructing Scientific Explanation of Galvanic Cell

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Abstract. This study aims at enhancing students' ability to construct scientific explanations of an electrochemistry content: galvanic cell. The teaching strategy was designed based on Vygotsky's (1978) internalization process, Johnstone's (1991) chemical representations, and two explanation models: the deductive nomological (DN) model proposed by Hempel and Oppenheim (1948) and the claim-evidence-reasoning (CER) model proposed by McNeill (2006). The critical action research processes were employed as the methodology by the first author researched on his teaching to do the self-study research and reflective-based research. Participants consist of fifty-nine students from two senior high schools in different academic years. Students' worksheets were analyzed to clarify their ability to construct scientific explanations. Also, classroom observations, student interviews, and opinions from two critical friends in each school were analyzed. The findings showed how students expressed their explanations through macroscopic, sub-microscopic, and symbolic representations. Likewise, the development of the educational media and the teaching strategy was shown.

Keywords: Scientific Explanation, Electrochemistry, Critical Action Research

INTRODUCTION

Literature review on senior high school electrochemistry education has revealed some problematic issues of this topic such as misconceptions and misunderstandings (Aydin, Friedrichsen, Boz, & Hanuscin, 2014; Brandriet & Bretz, 2014; Hamza, 2013; Rosenthal & Sanger, 2012; Hamza & Wickman, 2009; 2008; Potgieter, Harding, & Engelbrecht, 2008; Lee, 2007; Schmidt, Marohn, & Harrison, 2007; Bleicher, Tobin, & McRobbie, 2003; Schmidt & Volke, 2003; Ahtee et al, 2002; Sanger & Greenbowe, 2000; Ritchie, Tobin & Hook, 1997; Sanger & Greenbowe, 1997; Sanger, 1996). Electrochemistry also has been indicated as a complicated topic (Supasorn, 2015; Ahtee Asunta, & Palm al, 2002; Garnett & Treagust, 1992a; 1992b; Johnstone, 1991; Linford, 1961). To solve these pedagogical difficulties, this study therefore has attempted to assist students can construct a scientific explanation on an electrochemistry topic: the galvanic cell. Students' constructing an explanation for scientific phenomena is the central aim to learning science (Driver, Leach, Millar, and Scott, 1996). Likewise, the explanation is a significant core

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practice to improve science education in the United States of America (National Research Council, 2012; Pashler et al, 2007). In addition, Finland's core curriculum also proposes that explanation is one main method for chemistry instruction (Finish National Board of Education, 2003). Those have indicated that: explaining is the major behavior that science teachers should promote their students. This study, therefore, implements the developed instructional strategy fitted to the galvanic cell content to enhance students' ability to construct a scientific explanation.

THEORETICAL FRAMEWORKS

This study employed the Instructional Strategy designed for enhancing students' constructing scientific explanations proposed by Meedee and Yuenyong (2021). This instructional strategy has been backed by three theoretical frameworks: Vygotsky's (1978) internalization process. Second is Johnstone's (1991) three facets of content representations: macroscopic, sub-microscopic, and symbolic. The third is the two explanatory models: the Deductive Nomological (DN) proposed by Hempel and Oppenheim (1948), and the Claim-Evidence-Reasoning (CER) proposed by McNeill (2006). Based on those frameworks, the instructional strategy has been proposed as four stages. The details are illustrated in table 1; herewith, the codes of theoretical-based design that play a role as the backing ideas of each stage.

Table 1 Stages of the instructional strategy and codes of theoretical based design

Stage	Descriptions	Codes of theoretical based design
Stage 1	**Action on Macroscopic Phenomena** A hands-on group experiment about the galvanic cell, an electrochemistry content, is provided. This activity has been expected students to learn the macroscopic phenomena they can observe directly.	A01
Stage 2	**Learn through Classifying the Three Representations**	
	1) Writing and Drawing to learn The *Writing-Drawing on the Chemical-Electrical Representations* (WDCER) Worksheet (see appendix): the A4 size paper explicitly designed for the galvanic cell content is provided for every student to write and draw the findings from a group experiment. However, the direction on this worksheet is written in vocabularies that students are familiar with instead of science education terms such as macroscopic, sub-microscopic, or symbolic. Students have been expected to classify phenomena into three levels by individual forms rather than from their group summaries.	A01 A02
	2) Link all three representations The *Supporting Students' Understanding on Sub-microscopic phenomena* (SSUS) magnetic whiteboard (see appendix): A media is specifically designed to help students link the sub-microscopic and symbolic representations they made to a macroscopic phenomenon observed from their group experiment during stage 1. This media is made as a	A03 A04

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Stage	Descriptions	Codes of theoretical based design
	magnetic whiteboard to be stuck by the pictorial particle model sheets on that board; these model sheets can be moved because they are magnetic to represent the motion of particle levels such as electrons in the chemical reactions. Moreover, students can use magic markers to write or draw some more symbols or pictures. This board is expected to be an educational material as a scaffolding to assist students learn through classifying all three representations.	
	These activities are considered as the first step of Vygotsky's internalization process	B03
Stage 3	**Share Ideas between Group Discussions** The between-group discussion is provided, i.e., each group presents experiment findings and shows their ideas about all three representational phenomena, which is considered the second step of Vygotsky's internalization process.	A04 B03
Stage 4	**Construct a Scientific Explanation** Students are assigned to make their scientific explanation on the galvanic cell content, formed as a paper-based written scaffold is offered for every student: The Worksheet for *Supporting the Ability in Constructing Scientific Explanation* (SACSE), see appendix. Students need do this paper individually, which is considered the third step of Vygotsky's internalization process. Designing this written scaffolding is based on the abovementioned models: CER and DN explanation models through logical deduction.	B01 B02 B03

As table 1, the strategy has been proposed as four stages: Stage 1: Action on macroscopic phenomena. Stage 2: Learn through classifying the three representations. Stage 3: Share ideas between group discussions. Stage 4: Construct a scientific explanation. Each stage has the theoretical frameworks backing each learning activity. Those theoretical frameworks consist of two parts: Part A Learn through the chemical representations and Part B Constructing scientific explanations. Both parts are illustrated as seven abbreviation codes in table 1: A01-A04 and B01-B03. The details are shown below.

Part A: Learn through the chemical representations

A01 The roles of doing classroom experiments to serve the three facets of chemical representations

A classroom experiment has been designed as a hands-on activity. This activity has been planned for providing opportunities for students: 1) record the macroscopic as writing and drawing, 2) Draw some pictures for the sub-microscopic, and 3) write some alphabet to represent symbolic phenomena.

This galvanic cell experiment is expected to be the activities shown for all three representational phenomena at once classroom learning period.

A02 The sequence used of the three facets of chemical representations

Based on Johnstone's (1991) critiques, his idea was challenging for students who were novices for learning new science content because of the occurrence at the same time of such three phenomena. To help students learn electrochemistry easier, the idea of Lin,

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Son, and Rudd II (2016), therefore, has been referred to. They look at the chemical representations as to the different concreteness and abstractness. This idea is displayed in the figure below.

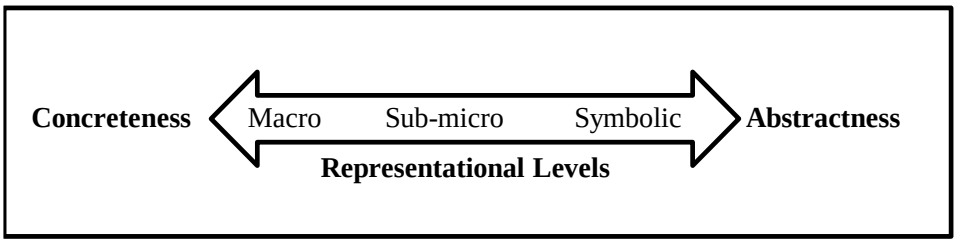

Figure 1 The concept of three-level (macroscopic, sub-microscopic, and symbolic) chemical representations is clarified by concreteness-abstractness of phenomena

As figure 1, the macroscopic, sub-microscopic, and symbolic representations are interpreted based on the concrete idea to abstract parallelly. Lin, Son, and Rudd II (2016) assumed that macroscopic was the most concrete phenomenon, sub-microscopic is moderate, while symbolic was the most abstract phenomenon. Their findings suggested that the effective sequence way of students' learning should be started from concrete to abstract.

Therefore, the instructional strategy designed for this study has provided students with learning at macroscopic first. They were assigned by doing a classroom experiment to observe directly and visibly. Then, they had to study the atomic and particle phenomena to respond to the idea of a sub-microscopic representation. The appropriated educational media, the WDCER worksheet, was added to promote students' understanding of representing the sub-microscopic phenomena. Finally, learning on symbolic representation would be provided respectively.

A03 Media as educational stuff designed to support learners link sub-microscopic and symbolic representations to macroscopic phenomena

Due to a macroscopic representation can be observed simply more than the other two facets. Linking the concepts of sub-microscopic and symbolic phenomena to macroscopic simultaneously may become a difficulty for students who are novices. Two kinds of media were offered to solve students' encountering. The WDCER worksheet was given to students individually during a hands-on experiment. The SSUS magnetic whiteboard was given one board per group after completing a hands-on experiment. This whiteboard has been expected to be the educational stuff as a scaffolding to help students learn through classifying all three representations. Moving and sticking the pictorial particle model sheets on the magnetic whiteboard together with writing and drawing some symbols could support the discussion process in each group. Moreover, they could use it to present their experiment findings to others.

A04 Roles of collaborative discussions from 1) the more capable peers and 2) the teacher's guidance during academic communications.

Based on Vygotsky's zone of proximal development, which concentrates on social interactions supports the human learning process, academic communication plays an important role in the classroom's teaching and learning. The communication acts may occur in many facets; however, the collaborative discussion is considered an easy method in the classroom because it can be conducted immediately if scientific issues arise during learning activities. This collaborative discussion process for a student was provided in two dimensions; viz., discussion with the more capable peers and with teachers' guidance. von Glaserfeld (1993) also stated the benefit of classroom communication: explaining something to a peer usually leads one to perceive more clearly. Therefore, both capable

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peers and a teacher were set to be scaffoldings for bridging that students' zone of proximal development.

Part B: Constructing scientific explanations

B01 Roles of the scaffolding particularly designed for the galvanic cell content

This study has aimed students to generate explanations scientifically for an electrochemistry content: galvanic cell. Writing and drawing were set as main modes to express explanations as paper-based: the SACSE worksheet. This worksheet was made to suggest a structure to promote students' expressing an explanation. For instance, the blank lines were provided for a written mode while the blank boxes were for drawing mode.

Those lines and boxes were arranged in the worksheet based on the logical deductive method of the DN explanation model, which has oriented that the explainers should start at a general summary of an electrochemistry phenomenon, then they need to add some more supporting details. This logical deductive way of explaining also accords to the CER model; it suggests that students begin proposing a Claim. Then, they need to give data and information as personal Evidence to support that claim based on the concept of chemical representations, i.e., macroscopic evidence, sub-microscopic evidence, and symbolic evidence. Finally, students are required to express their Reasons to link those evidence to the claim.

The educational scaffolding worksheet was designed as individual paper per person to serve the concept of Vygotsky's internalization process; details are in the following topic B03. This scaffolding played a role as a suitable assisting tool to help students explain electrochemical phenomena scientifically based on their meaning-making through classroom activities. However, this scaffolding should be moved out gradually after students are more strong ability in constructing explanations.

B02 Effects of students' making the meanings through the representations for explanations

Johnstone' representations have been considered as a significant influence on chemistry (Taber, 2013a; 2013b; Talanquer, 2011; Gilbert & Treagust, 2009), and also is a unique notion for research in chemistry education effectively (Wu & Yeziersk, 2022; Kelly, Akaygun, Hansen, Villalta-Cerdas, & Adam, 2021; Matijašević, Korolija & Mandić, 2016; Rau, 2015; Taskin, Bernholt, & Parchmann, 2015; Adadan, 2014; Dumon & Mzoughi-Khadhraoui, 2014; Lewthwaite, 2014; Philipp, Johnson, & Yezierski, 2014; Dangur, Avargil, Peskin, & Dori, 2014; Lewis & Bodner, 2013; Antonoglou, Charistos, & Sigalas, 2011). Therefore, it has been used to support students in constructing chemical explanations.

The concept of representations is set as a central idea to clarify electrochemical phenomena into three aspects of claim, e.g., macroscopic claim, sub-microscopic claim, and symbolic claim (see a triangle in figure 2). Then, each claim must be supported by the scientific evidence sufficiently. To link those evidence to that claim, reasoning must be provided logically, which in this study proposes the deductive method based on the essay of Hempel and Oppenheim (1948). The whole relational process in figure 2 is considered the theoretical framework that will be used as the basic concept for developing an instructional strategy for enhancing students' constructing of scientific explanations in electrochemistry of this study.

Although having this framework is considered a benefit for study on explanation ability, employing it in classroom teaching needs to be concerned with providing strategies for individual construction of knowledge. Vygotsky's internalization process, therefore, needs to be discussed.

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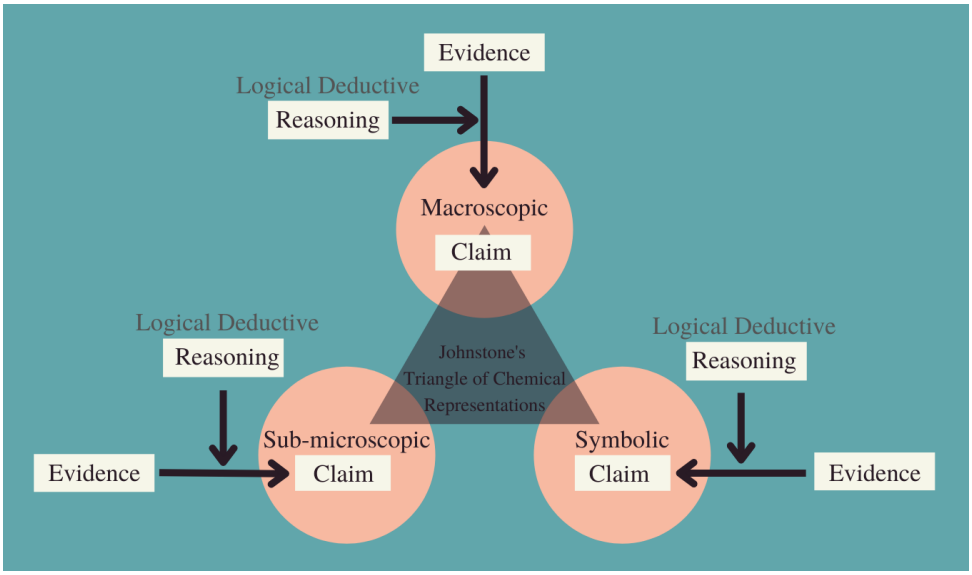

Figure 2 Theoretical framework to measure students' scientific explanation ability using the multi-faceted content representations reinforces the DN and CER explanatory models.

B03 Roles of the three steps of Vygotsky's internalization process

The supporting process of constructing an explanation of this study has employed the three internalization processes proposed by Vygotsky (1978). After students encounter the new *sign-using activity* (p.57), which can be illustrated as the new electrochemistry concept provided in the classroom, then (1) an external activity is reconstructed and begins to occur internally. Students have been assigned to experiment at this stage, which can be illustrated as the external activity of this internalization process. In the case of this study, it is stage 1: action on macroscopic phenomena.

(2) An interpersonal process is transformed into an intrapersonal one. This second step can be illustrated as stage 2 and stage 3 of this study, i.e., after finishing the interpersonal process in stage 1, students need to learn through classifying the three representations as a personal assignment, the intrapersonal process. (3) the results of transforming an interpersonal process into an intrapersonal one result from a long series of developmental events. This third step can be illustrated as stage 4 in the instructional strategy of this study. After finishing a personal assignment of classifying the three representations, all groups in the classroom are persuaded to share ideas (stage 3) about their personal learnings. Then, they must construct an explanation (stage 4) as a personal activity.

These three steps of the internalization are the process of dialogue into inner speech and thought through providing both psychology and linguistics (Bruner, 1962), which is different from other kinds - cognitive and radical - of constructivism, especially to the behaviorist approach, which ignores the complexities of the internal psychological process (Wertsch & Stone, 1985). However, the findings of this study would back up this instructional strategy could encourage students' ability to construct scientific explanations of electrochemistry.

METHODOLOGY

The reflective-based research and the self-study research had been operated for this study, i.e., the first author performed a chemistry teacher role and studied his teaching. The critical action research process: plan, act, observe, reflect, proposed by Kemmis, McTaggart, and Nixon (2013), was used as a core concept to implement this instructional strategy into the science classroom, including collecting the data and analyzing the classroom phenomena.

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Participants

Participants of this study were senior high school students from two schools in the same province in Thailand but in different districts (35 kilometers far from each other's). Both are not different levels defined by the science national test score, but school 1 had a slightly higher average mean score than school 2.

School 1 was the eleventh-grade students in semester 2 of 2017 (November 2017-March 2018). School 2 was the twelfth-grade students in semester 1 of 2018 (May-September 2018). There were 40 students in School 1, and only 30 students had attended all three periods (all four stages of the instructional strategy). While the number of students in school 2 is 35, only 29 students had thoroughly attended. Thus, the total number of participants is 59 students.

Because of privacy, this essay has avoided declaring names and genders. So, they all will be called other codes. For example, a student who is a number 1 of school 2 will be called Sc2No01; likewise, a student who is a number 2 will be called Sc2No02, and others will be called like this respectively until the last number who will be called Sc2No35.

Furthermore, the critical reflective peers were conducted during the steps of observing, reflecting, and re-planning as a method to back the study's trustworthiness. A critical reflective peer in School 1 has graduated with a Master of Science (M.S.) in Chemistry for Teacher and has 12 years of experience as a chemistry teacher. While a critical peer in School 2 has graduated with a Doctor of Philosophy (Ph.D.) in Educational Research and Evaluation and has 14 years of experience as a chemistry teacher. Their suggestions were beneficial for improving learning activities of this study significantly. This method of peer debriefing process is one of five elements to make research's credibility which is the parallel of the internal validity (Lincoln & Guba, 1985; Guba & Lincoln, 1989; Erlandson, Harris, Skipper, & Allen, 1993).

Implementing the four stages in the electrochemistry classroom

This content, galvanic cell, was taught in three periods through the four stages of this instructional strategy (50 minutes/period). Stages 1-3 were managed for two consecutive periods on the same day. While stage 4 was managed for one period on another day but the same week.

In stage 4, students had learned to construct an explanation by another question different from stages 1-3, i.e., they studied the production of electric current from a redox (reduction and oxidation) reaction. While stage 4, they were asked a question: Which metal will rust or corrode if two half cells of $Cu(s)|Cu^{2+}(aq)$ and $Zn(s)|Zn^{2+}(aq)$ are linked by wire and salt bridge? In addition, the electrodes, and electrolytic solutions in stages 1-3 were used several elements such as Aluminium: $Al(s)|Al^{3+}(aq)$, Copper: $Cu(s)|Cu^{2+}(aq)$, Magnesium: $Mg(s)|Mg^{2+}(aq)$, and Zinc: $Zn(s)|Zn^{2+}(aq)$ which students could choose and pair independently on condition that the electrolytic solutions must fit the electrodes but, in stage 4, they were asked merely copper and zinc.

Data collection and analysis

Translating the worksheets that students constructed their scientific explanations has been used the major and minor elements proposed by Meedee and Yuenyong (2021) as table 2. The major element contains claim, evidence, and logical deductive reasoning based on the DN and CER explanation models proposed by Hempel and Oppenheim (1948) and McNeill (2006). The minor element contains the three chemistry content representations proposed by Johnstone (1991): macroscopic, sub-microscopic, and symbolic. These elements are the basic structure to measure the students' explaining ability of this study through the rubric score specific to this electrochemistry content: galvanic cell (see an appendix).

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Table 2 The major and minor elements of the specific rubric score for analyzing the explanation ability, codes for analyzing, and score of each element

Major Elements	Minor Elements	Codes for Analyzing	Total Scores
C: Claim	-	C	2
E: Evidence	Ma: Macroscopic	MaE	3
	Su: Sub-microscopic	SuE	3
	Sy: Symbolic	SyE	3
R: Reasoning as logical deduction	Ma: Macroscopic Su: Sub-microscopic Sy: Symbolic	R	4
Total		2C-(3Ma-3Su-3Sy)E-4R = 15	

As table 1, the Claim is abbreviated as C, and the total score is 2. The Evidence is abbreviated as E and is split into three sub-elements: macroscopic evidence, sub-microscopic evidence, and symbolic evidence. The total score of each sub-element is 3 points, resulting in the total score of E being 9. Thirdly, the Reasoning is abbreviated as R, and the total score is 4. Students who could express their full explaining score would get the category of 2C-(3Ma-3Su-3Sy)E-4R, of which the total score is 15.

FINDINGS

The findings revealed what we learned from action research for students' scientific explanation ability in the learning about galvanic. The section will clarify the examining categories of students' scientific explanation ability and then discuss what we learned to change teaching and issues of improving students' scientific explanation ability.

1. Categories of students' scientific explanation ability

After we finished all three periods of the four stages of the instructional strategy, the students' worksheet for Supporting the Ability in Constructing Scientific Explanation (SACSE) were scored to represent the ability to construct a scientific explanation for galvanic cell. Those scores as the categories are shown in table 3.

As table 3, after learning this instructional strategy, eight students could get a full score of the 2C-(3Ma-3Su-3Sy)E-4R category. In addition, 79.66% of all students scored more than 10 points (48 students: SC1=28, SC2=19), whereas merely 20.34% scored no more than 10 points (12 students: SC1=2, SC2=10).

Besides, students from both schools had expressed their explanations as 22 categories: 11 categories for school 1 and 14 for school 2. Most students (93.33%) could provide all five of the explanatory elements in table 1: C, MaE, SuE, SyE, and R. There were merely four students (6.66%) still be not complete in providing fully.

According to the results of students' scientific explanation in the table 2, the researchers and colleagues reflected how to improve students' ability. The reflection was developed through the after-teaching reflection, students' tasks, and student interviewing. This reflection allowed us to learn what and how to improve students' scientific explanation ability in learning about galvanic as following issues. These included improving the sub-microscopic media via atomic size and radii based-designed, the pictorial sub-microscopic evidence for supporting scientific explanations, and adjusting the stages of the instructional strategy.

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Table 3 Frequency of students' categories of scientific explanation ability and frequency of students in each category

Scores	Categories of students' scientific explanation ability [2C-(3Ma-3Su-3Sy)E-4R=15]	Frequency of students		Frequency of two schools' students (%)
		School 1	School 2	
15	2C-(3Ma-3Su-3Sy)E-4R	6	2	47 (79.66)
14	2C-(3Ma-3Su-3Sy)E-3R	5	4	
13	2C-(3Ma-3Su-3Sy)E-2R	1		
	2C-(3Ma-2Su-3Sy)E-3R	8		
	2C-(2Ma-2Su-3Sy)E-4R	2		
	2C-(2Ma-3Su-3Sy)E-3R		1	
	2C-(3Ma-3Su-3Sy)E-2R		2	
12	2C-(3Ma-2Su-3Sy)E-2R	2		
	2C-(3Ma-1Su-3Sy)E-3R	2		
	2C-(2Ma-3Su-3Sy)E-2R		2	
11	2C-(2Ma-2Su-3Sy)E-2R	1	8	
	2C-(2Ma-1Su-3Sy)E-3R	1		
10	2C-(1Ma-1Su-3Sy)E-3R	1		12 (20.34)
	2C-(1Ma-2Su-3Sy)E-2R		3	
	2C-(2Ma-2Su-1Sy)E-3R		1	
	2C-(3Ma-3Su)E-2R		1	
9	2C-(1Ma-2Su-1Sy)E-3R		1	
	2C-(1Ma-3Su-2Sy)E-1R		1	
	2C-(2Ma-3Su)E-2R		1	
8	2C-(1Ma-1Su-2Sy)E-2R	1		
7	2C-(2Ma-2Su)E-1R		1	
4	2C-(1Ma-1Su)E		1	
Total	22 categories School 1=11, School 2=14	30	29	59 (100.00)
		59		

2. What we learned how to improve students' scientific explanation ability

The teaching about galvanic in two schools suggested the researchers to learn some issues for improving students' scientific explanation ability. These included improving the sub-microscopic media via atomic size and radii based-designed, the pictorial sub-microscopic evidence for supporting scientific explanations, and adjusting the stages of the instructional strategy. Each issue will be discussed as below.

Improving the sub-microscopic media: via the atomic size and radii based-designed

During school 1's students were sharing their ideas in a whole-class discussion of stage 3, the first author, as a chemistry teacher, noticed that some of them said: "*the dented atom*" to represent an ion in their group SSUS magnetic whiteboard. This word made us realize that the educational media might mislead them. A sample of students' works on the whiteboard is shown in figure 3.

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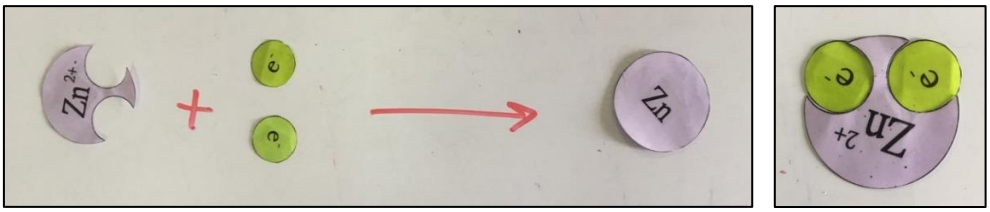

A reaction of: $Zn^{2+}(aq) + 2e^{-} \rightarrow Zn(s)$ "*analogy as a frog*"

Figure 3 Some students' works from the activity of the SSUS magnetic whiteboard

As figure 3, A student (Sc1No06) described his/her group magnetic whiteboard that (1) "*this dented atom of zinc gains 2 electrons; it will become a full atom like this*" and (2) "*if we move green electrons into the dented positions of an ion; it will change to be the normal atom, not be the ion anymore. Its shape likes a frog*". This sentence made everyone laugh, including a reflective peer. However, as the teacher roles, the first author realized that this might make misconceptions in learning. This error was like Kelly, Barrera, and Mohamed's (2010) findings that found the misconceptions in sub-microscopic from undergraduate students. Gkitzia, Salta, & Tzougraki (2020) also found that students got problems in solid-state particle structure. In addition, the mistake of these model sheets was also liked the study of Rosenthal & Sanger (2012) that misconception came from their media: the computer animation.

Likewise, analyzing in school 1 students' scientific explanation ability focusing on three types of evidence was found the sub-microscopic (SuE) was the lowest average score than others, see figure 4 and table 4. This indicated that there was some problems in this element.

Therefore, we (a school 1 critical friend and I) interpreted on students' providing sub-microscopic evidence ability that: their analogy of the SSUS magnetic whiteboard' s model sheets (as a frog) were the misconception about atomic size and radii. This mistake could spread to other students. So, the first author immediately confessed to them all that: these dented ions were wrong. Therefore, we decided to cancel those dented model sheets for the subsequent action research cycle.

In the issue of atomic size and radii, almost all elements in high school electrochemistry are often metals. Those metallic elements will regularly lose some electrons rather than gain electrons, becoming the positive charge ions: cations. Those cations are smaller than their parent atoms. Hence, the atomic model sheets had been revised based on the concept of the atomic size that would increase when gaining electrons and decrease when losing electrons. Because this case is cations, if elements become ions, they will be smaller. A sample of the model sheets is illustrated as real size, details are in the following figure.

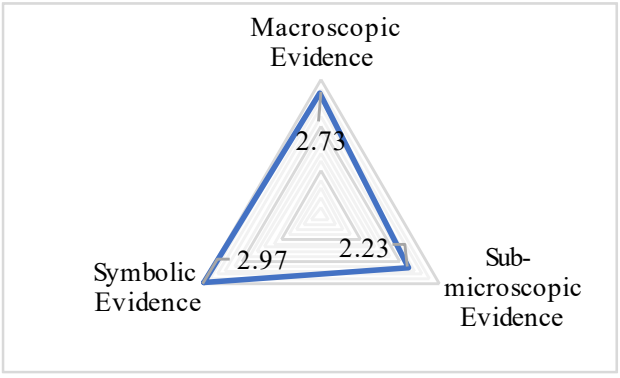

Figure 4 School 1's scientific explanation ability mean score of macroscopic, sub-microscopic, and symbolic evidence

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Table 4 School 1's scientific explanation ability mean scores, standard deviations, and percentage

Scores	Categories of students' scientific explanation ability [2C-(3Ma-3Su-3Sy)E-4R=15]	Frequency of students		Frequency of two schools' students (%)
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	2C-(3Ma-3Su)E-2R		1	
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	2C-(2Ma-3Su)E-2R		1	
8	2C-(1Ma-1Su-2Sy)E-2R	1		
7	2C-(2Ma-2Su)E-1R		1	
4	2C-(1Ma-1Su)E		1	
Total	22 categories School 1=11, School 2=14	30	29	59 (100.00)
		59		

* Percentages compared to the full scores of each element.

In figure 5, the initial design of a zinc atom and its ion is in the first column: the radius of atomic and ionic forms are the same size without considering the actual sizes. In addition, the ionic form made a difference to its parent atoms by (1) adding the two-plus symbol, becoming Zn^{2+}, and (2) making the model sheets as the two holes fit an electron model sheet size. While the revised version of those model sheets generated the atomic and ionic forms as different sizes based on the scientific data, the atomic radius of Zn is 120 pm which is bigger than the ionic radius of Zn^{2+}: 80 pm. Moreover, both forms have been added to their simple electron configurations to clarify the numbers of electron shells or energy levels of electrons.

In the case of the zinc atom: 30 electrons, there are four shells of $1s^2$ $2s^2$ $2p^6$ $3s^2$ $3p^6$ $4s^2$ $3d^{10}$ in ascending order of orbital energies or [2 8 18 2] in the simple form. In the ionic form, zinc loses 2 electrons to form Zn^{2+}, so removing 2 electrons from the $4s^2$ becomes total 28. Its electron configuration can be shown as $1s^2$ $2s^2$ $2p^6$ $3s^2$ $3p^6$ $3d^{10}$ or [2 8 18] in the simple form. Students were expected to notice those numbers of shells; readily,

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they should notice that Zn was bigger than Zn^{2+} because of their number of electrons' shells, i.e., Zn loses 2 electrons of its valence shell, resulting in only three shells remaining.

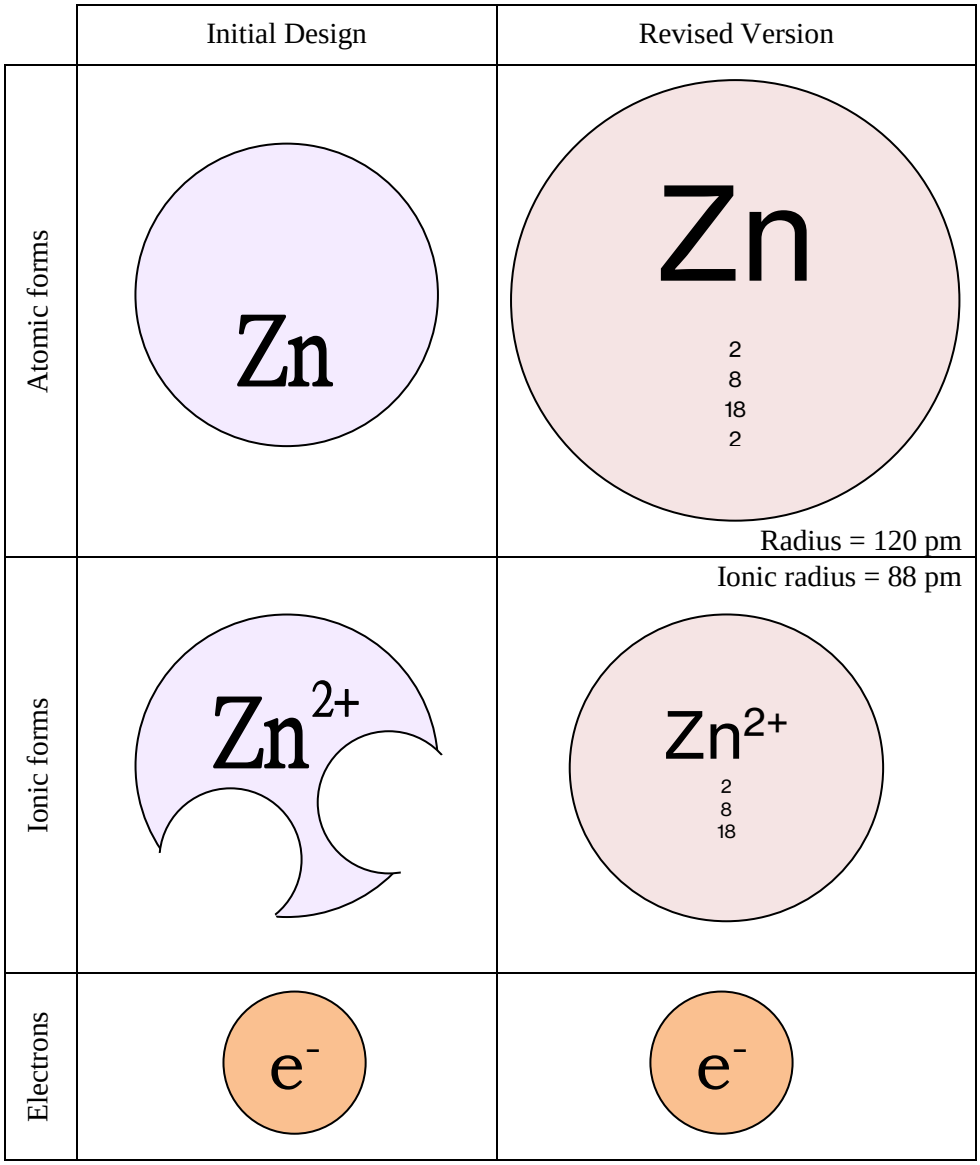

Figure 5 The atomic and ionic model sheets that are adjusted based on the concept of atomic size and radii, and electron configuration. (Real size for A4 paper printing)

After employing this revision of model sheets for using in the SSUS magnetic whiteboard, the school 2 students' sub-microscopic misconceptions were not found during the observation or reflection steps of the action research process. In stage 2 of this instructional strategy, we found they represented the electrochemical phenomena of galvanic cell by displaying the electron transferring for both two electrodes: anode and cathode. The sample are shown in figure 6 which is the works of a Sc2No12 student' the Writing-Drawing on the Chemical-Electrical Representations (WDCER) worksheet.

As figure 6, a Sc2No12 student got 14 points of the explaining ability as a category of 2C-(3Ma-3Su-3Sy)E-3R. S/he expressed sub-microscopic ideas by writing and drawing the simple electron configurations of aluminum and magnesium to clarify:

(1) The *thickening* of aluminum metal in the cathode that was the reduction reaction by illustrating as a puffed area; see a bottom left arrow. S/he drew five or six small

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circles to represent a macroscopic phenomenon learned in the stage 1 of the instructional strategy. Based on scientific data, Al^{3+} ions in the liquid electrolytic solution of aluminum sulphate [$Al_2(SO_4)_3$] gains three electrons becoming the aluminum metal (solid state). These can be written as a chemical reaction as [$Al^{3+}(aq) + 3e^- \rightarrow Al(s)$] which s/he could write correctly. Both $Al^{3+}(aq)$ and Al(s) were represented by marking an ellipse around the simple electron configurations of each as Al^{3+} = (2 8), and Al = (2 8 3) respectively. Note: However, there is a misconception about the numbers of losing electrons which is $3e^-$, should not be $2e^-$ like s/he wrote.

(2) The *corrosion* of magnesium metal in the anode that was the oxidation reaction by illustrating as the dent area; see a bottom right arrow. S/he drew five or six small circles to represent a macroscopic phenomenon learned in the stage 1 of the instructional strategy. Based on scientific data, the magnesium metal [Mg(s)] lost two electrons becoming $Mg^{2+}(aq)$ ions, all is in the liquid electrolytic solution of magnesium sulphate (solution). These can be written as a chemical reaction as [$Mg(s) \rightarrow Mg^{2+}(aq) + 2e^-$] which s/he could write correctly. Both $Mg^{2+}(aq)$ and Mg(s) were represented by marking an ellipse around the simple electron configurations of each as Mg^{2+} = (2 8), and Mg = (2 8 2) respectively. These indicated the benefits of the SSUS whiteboard as a scaffolding media to encourage students' learning in a sub-microscopic representation. This finding accords to the study of Berg, Orraryd, Pettersson, & Hultén (2019), who expected them to re-represent their understanding of chemical phenomena by assigning students to make physical models of sub-microscopic particles tools for chemical reasoning. We propose that this educational media's new design could advantage students to understand the authentic scientific phenomena of atomic size and radii more closely. Also, it has significantly played a role as a tool to assist students can represent the particles (atomic, ionic, and molecular) levels as the sets of evidence to support their explanations. Hence, the students' sub-microscopic evidence would be focused on.

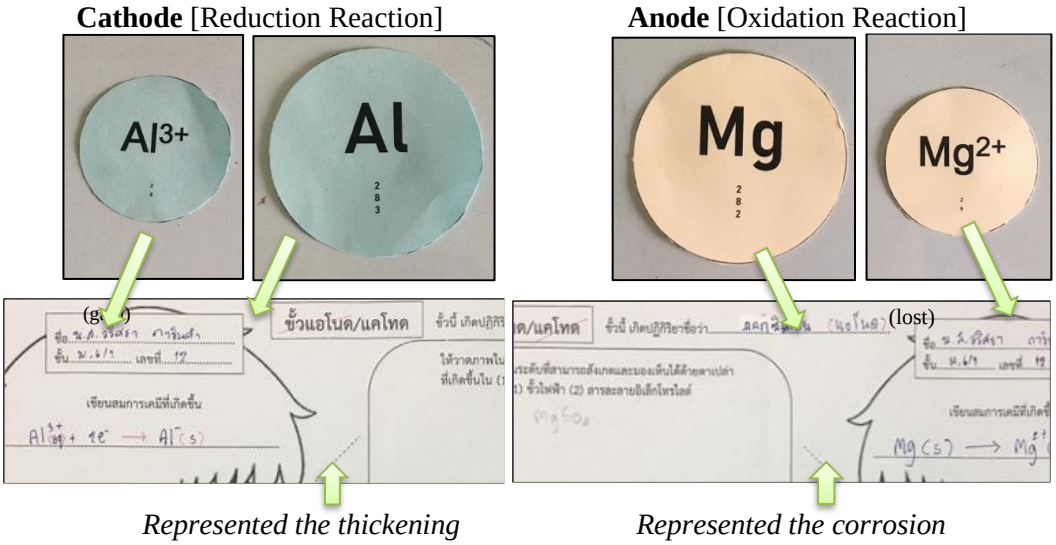

Figure 6 The Sc2No12 student's using the concept of the electron configuration from the revising version of model sheets to link macroscopic to sub-microscopic phenomena.

Pictorial sub-microscopic evidence for supporting scientific explanations

After we finished all three periods of the four stages of the instructional strategy, SACSE worksheet (details of this worksheet were shown in table 1 and appendix) from all 59 students were analyzed on their sub sub-microscopic evidence. Findings were shown as table below.

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As table 5, students represented their ideas of sub-microscopic evidence by 50 students making the pictorial mode together with the written mode. While 9 students used the inappropriate pictorial mode to support their scientific explanations, in this group, 3 students made the inappropriate pictures but good in writing and 6 students made the inappropriate evidence in both pictorial and written modes. We did not find any students expressing their sub-microscopic ideas by a single mode of writing or drawing.

Table 5 Frequencies and percentages of students in types of pictorial sub-microscopic evidence

Types of Pictorial Sub-microscopic Evidence			Scores	Categories	F		Total (%)	Grand total (%)
					Sc 1	Sc 2		
Using pictorial mode	I	Chemical Equation pictorial	15	2C-(3Ma-3Su-3Sy)E-4R	3		15 (25.42)	50 (84.75)
			14	2C-(3Ma-3Su-3Sy)E-3R	3			
			13	2C-(3Ma-2Su-3Sy)E-3R	7			
				2C-(2Ma-2Su-3Sy)E-4R	1			
			12	2C-(3Ma-2Su-3Sy)E-2R	1			
	II	Dynamic pictorial	15	2C-(3Ma-3Su-3Sy)E-4R	1		15 (25.42)	
			14	2C-(3Ma-3Su-3Sy)E-3R	1	1		
			13	2C-(3Ma-3Su-3Sy)E-2R	1			
				2C-(3Ma-2Su-3Sy)E-3R	1			
				2C-(2Ma-3Su-3Sy)E-3R		1		
			12	2C-(2Ma-3Su-3Sy)E-2R		1		
			11	2C-(2Ma-2Su-3Sy)E-2R	1	5		
			10	2C-(2Ma-2Su-1Sy)E-3R		1		
			9	2C-(1Ma-2Su-1Sy)E-3R		1		
	III	Macroscopic pictorial	14	2C-(3Ma-3Su-3Sy)E-3R		2	8 (13.56)	
			13	2C-(3Ma-3Su-3Sy)E-2R		1		
			11	2C-(2Ma-2Su-3Sy)E-2R		3		
			10	2C-(1Ma-2Su-3Sy)E-2R		1		
			7	2C-(2Ma-2Su)E-1R		1		
	IV	Dynamic + Macroscopic pictorial	15	2C-(3Ma-3Su-3Sy)E-4R		2	7 (11.86)	
			14	2C-(3Ma-3Su-3Sy)E-3R		1		
			13	2C-(3Ma-3Su-3Sy)E-2R		1		
			10	2C-(3Ma-3Su)E-2R		1		
			9	2C-(1Ma-3Su-2Sy)E-1R		1		
				2C-(2Ma-3Su)E-2R		1		
	V	Notational pictorial	15	2C-(3Ma-3Su-3Sy)E-4R	2		5 (8.47)	
			14	2C-(3Ma-3Su-3Sy)E-3R	1			
			13	2C-(2Ma-2Su-3Sy)E-4R	1			
			12	2C-(3Ma-2Su-3Sy)E-2R	1			
Inappropriate	n/a (1)	Inappropriate pictures but good in writing	12	2C-(2Ma-3Su-3Sy)E-2R		1	3 (5.08)	9 (15.25)
			10	2C-(1Ma-2Su-3Sy)E-2R		2		
	n/a (2)	Inappropriate evidence	12	2C-(3Ma-1Su-3Sy)E-3R	2		6 (10.17)	
			11	2C-(2Ma-1Su-3Sy)E-3R	1			
			10	2C-(1Ma-1Su-3Sy)E-3R	1			
			8	2C-(1Ma-1Su-2Sy)E-2R	1			
			4	2C-(1Ma-1Su)E		1		
Total					30	29	59	

n/a = Not available, F=Frequencies, Sc.1=School 1, Sc.2=School 2

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Comparisons between two groups of students who illustrated sub-microscopic evidence by (1) using pictorial mode and (2) using inappropriate pictorial mode were shown in the figure below.

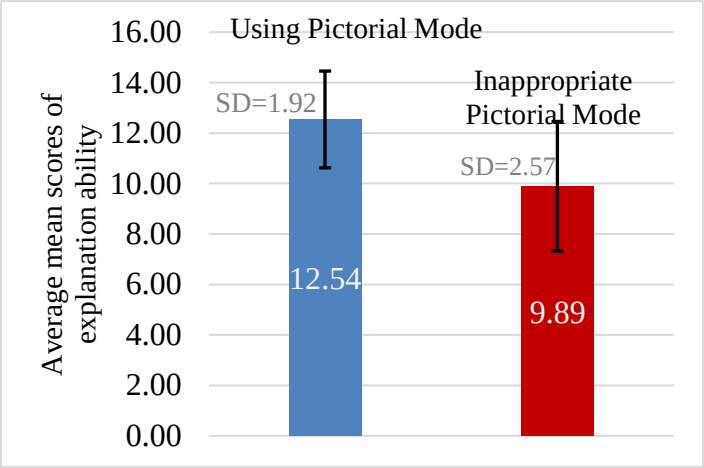

Figure 7 Average mean scores and standard deviations of the explanation ability divided by two group of students who illustrated sub-microscopic evidence by (1) using pictorial mode and (2) making inappropriate pictorial mode

In figure 7, we found that a group of students who made sub-microscopic evidence using pictorial mode got higher average mean scores than those who made inappropriate pictorial mode. This finding indicates that representing phenomena by drawing pictures effectively supports students' ability to construct a scientific explanation of the galvanic cell content.

In addition, focusing on a group of 50 students who made pictorial mode, we found five different types of sub-microscopic representation:

I. Chemical Equation pictorial: 25.42% with 5 categories
II. Dynamic pictorial: 25.42% with 9 categories
III. Macroscopic pictorial: 13.56% with 5 categories
IV. Dynamic + Macroscopic pictorial: 11.86 with 6 categories
V. Notational pictorial: 8.47% with 4 categories

The details and samples of each type are illustrated in the table below.

These findings of the five different types of students' making sub-microscopic evidence can emphasize the importance of several kinds of learning styles. Science educators and teachers should consider the students' individual differences and the contexts of each school. Therefore, the stages of this instructional strategy have also been adjusted to fit classrooms' occurrences as phenomenological-based designs.

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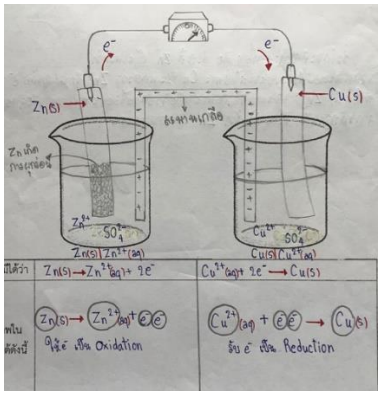
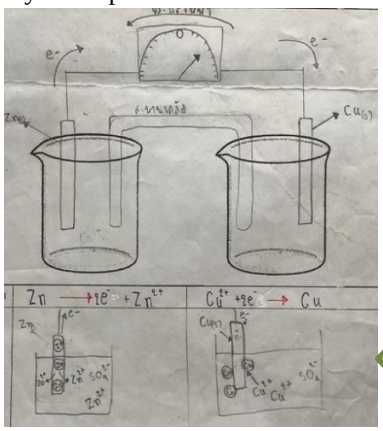
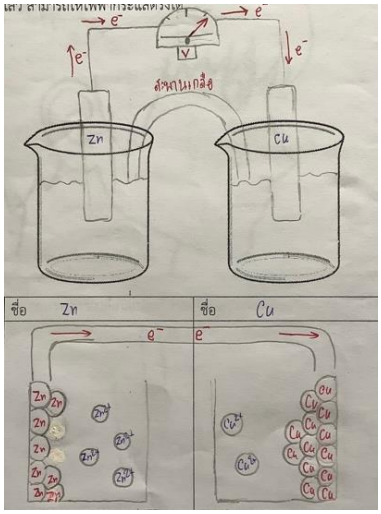
Table 6 Samples of five types of pictorial sub-microscopic evidence

Types of pictorial sub-microscopic evidence	Descriptions
I. Chemical Equation pictorial 	**Sc1No23**: 2C-(3Ma-3Su-3Sy)E-3R=14 Although students have already wrote chemical equations of two reaction of a reduction and an oxidation in symbolic evidence blank, at the sub-microscopic has still been represented as chemical equations. Students made equations as circles to represent atoms, ions, and electrons as pictorial.
II. Dynamic pictorial 	**Sc1No33**: 2C-(3Ma-3Su-3Sy)E-4R=15 Students made sub-microscopic evidence by drawing arrows to show the flow of losing and gaining electrons of anode and cathode respectively. In addition, some symbols of atoms and ions also were shown to clarify their ideas.
III. Macroscopic pictorial 	**Sc2No01**: 2C-(3Ma-3Su-3Sy)E-2R=13 Students of this group made sub-microscopic evidence by making atomic and ionic pictures as many circles. Those pictures were proposed based on the thickening and the corrosion of metals which were the macroscopic phenomena they can observe in classroom activities.

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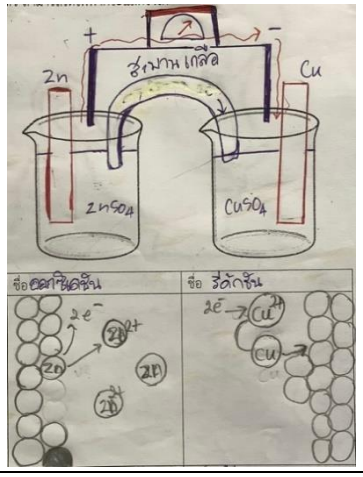
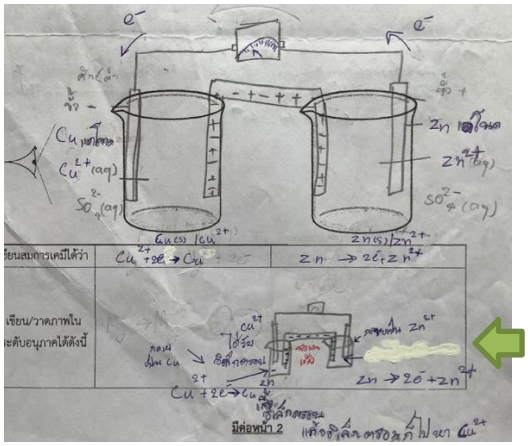
Types of pictorial sub-microscopic evidence	Descriptions
IV. Dynamic + Macroscopic pictorial 	**Sc2No03**: 2C-(3Ma-3Su-3Sy)E-4R=15 Students illustrated their sub-microscopic ideas by making arrows to show the flow of losing and gaining electrons on oxidation and reduction reactions: (type II dynamic), together with the thickening and the corrosion of metals (type III macroscopic phenomena).
V. Notational pictorial 	**Sc1No06**: 2C-(3Ma-3Su-3Sy)E-4R=15 Students of this group used series of written symbols and arrows to show their ideas of sub-microscopic representation. Some sentences or phrases were written to support their concepts of gaining and losing electrons. In addition, two chemical equations of oxidation and reduction also were illustrated.

Adjusting the stages of the instructional strategy

In stage 1 of the instructional strategy, each students' group could themselves design independently to pair any kinds of 4 metals: aluminium, copper, magnesium, and zinc to their appropriated electrolytic solutions (we provided more than four kinds). If an electrolytic solution is misappropriated to its metal, the reaction might not happen.

Our critical peer at School 2 seriously reminded us about this independence because two from 6 groups chose the wrong electrolytic solutions. S/he suggested that the first author should clarify the experiment's details more clearly. However, this was our will. We wanted them to learn from their mistakes. This wrong selection affected their experiments were not working. However, we supervised them to check their private group's voltmeter during class. At the same time, the first author persuaded other groups to share the experimental results, and both groups had learned from those friends' experiments (each group had chosen different kinds of metals). These two groups could experiment again smoothly, and it was working.

Based on the theoretical frameworks, our persuasion to students to share their ideas should do in stage 3: conducted under the concepts of Vygotsky's internalization process. However, the stage of Share Ideas between Group Discussions had also occurred during stage 1: Learn through Macroscopic Phenomena. This finding pointed out the overlapping of stages 3 to others. We want to argue that sharing ideas can be conducted in any stage because students learn in the same room where each group can see each other. The process of sharing ideas can generally occur and all times naturally. The stages of this instructional can be employed flexibly; hence, we would like to propose the Revised

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Version of the strategy together with the Original Version. Science educators and teachers can employ any versions based on contexts or classroom situations. Both could be illustrated in figure 8.



Figure 8 Original and Revised versions of the instructional strategy

Conclusions

The findings of this study found the importance of using a pictorial mode together with a written mode as the evidence that can support students' explanation ability on scientific phenomena such as electrochemistry which is a complicated topic. In addition, several types of students' expressing sub-microscopic ideas have indicated the students' individual difference and several kinds of learning styles should be concerned by chemistry teachers and educators.

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