Asia Research Network Journal of Education
Vol. 1, No. 3, pp. 179 - 204, Sep. – Dec. 2021

Redox Reaction Teaching and Learning for Enhancing Students' Ability in Constructing Scientific Explanations through Action Research

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Received: 30 Nov 2021 Revised: 28 Dec 2021 Accepted: 31 Dec 2021

Abstract. This study aims to enhance senior high students' ability to construct scientific explanations for redox reactions, a sub-topic in electrochemistry. Methodology was conducted based on the self-study research and reflective-based research in which the first author research on his teaching. This idea relates to the spiral research processes that consist of many cycles of Plan, Act, Observe, and Reflect (PAOR) as a long spiral at two schools in a province in Thailand but different districts. Participants included 39 school 1 students and 31 school 2 students. School 1 was conducted along the 2nd semester, November to March, of the academic year 2017. School 2 was conducted along the 1st semester, May to September, of the academic year 2018. The instructional strategy of this study was designed based on three theoretical ideas, i.e., 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 instructional strategy was proposed as four stages. After being implemented in classrooms, some elements of the rubric score to measure the students' scientific explanations have been revised based on the reflecting step of the action research process. Moreover, the details of adjusting the worksheets and other media were discussed. Also, this study reported how students learn to construct their explanations scientifically.
Keywords: Scientific Explanation, Electrochemistry, Action Research

1. Introduction

Electrochemistry has been indicated as a complicated topic (Supasorn, 2015; Ahtee Asunta, & Palm al, 2002; Garnett & Treagust, 1992a; 1992b; Johnstone, 1991; Linford, 1961). Although there are endeavors from many researchers to improve both the teaching and learning processes, the literature review has indicated some educational problems such as misconception and misunderstanding especially at the senior high school level (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

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& Greenbowe, 2000; Ritchie, Tobin & Hook, 1997; Sanger & Greenbowe, 1997; Sanger, 1996).

These pedagogical problems have indicated that electrochemistry is a concept in which many high school students experience difficulties in learning. To solve this problem, assisting students' constructing an explanation on electrochemistry should be focused on because explaining the natural phenomena is a central aim of science (Driver, Leach, Millar, and Scott, 1996) that pupils should succeed. In addition, the explanation is also stated as a significant core practice to improve learning in the United States of America (National Research Council, 2012; Pashler et al, 2007), and Finland's core curriculum specifies that explanation is one main method for chemistry instruction as well (Finish National Board of Education, 2003). Those have indicated explaining is the principal behavior that science educators and teachers should support; therefore, this study implements the developed instructional strategy fitted to redox reaction content to enhance students' ability to construct scientific explanations.

2. Methodology

This study was conducted based on the self-study research and reflective-based research in which the first author research on his teaching. The critical action research process proposed by Kemmis, McTaggart, & Nixon (2013) was chosen to implement the instructional strategy in the senior high school electrochemistry classrooms because the operations of action research are suitable for educational actions and are flexible i.e. the practical processes can be adjusted during the research conductions (Carr & Kemmis, 1983). This idea relates to the spiral research processes that consist of many cycles of Plan, Act, Observe, and Reflect (PAOR) as a long spiral at two schools in a province in Thailand but different districts. Both schools are the same school-type (secondary school) where schooling for 7th-12th grade: 13-18 years old. Both are medium-sized institutions, numbers of classrooms in each grade are the same; 4 classrooms. Therefore, implementing the instructional strategy developed at the first school can be used at the second school. Notably, both schools have been grouped as the same level by considering Thailand's national test score in Science (O-NET: Ordinary National Educational Test) of the last three years before conducting this research. Hence, each school's participating students' ability would be trusted as similar performance, but the first school had slightly higher scores.

Participants

Participants included 39 school 1 students and 31 school 2 students. School 1 was conducted along the 2nd semester, November to March, of the academic year 2017. A chemistry teacher at school 1 was asked to observe this class to play a role as the critical reflective peer at the observe, reflect, and re-plan of the action research process. S/he has graduated with a Master of Science (M.S.) in Chemistry for Teacher and has 12 years of experience as a chemistry teacher. Suggestions from his/her were used to improve the instructional strategy for the next schools. School 2 was conducted along the 1st semester, May to September, of the academic year 2018. A chemistry teacher at this school was also asked to observe the class to play a role as the critical reflective peer at the observe, reflect, and re-plan of the action research process. S/he has graduated with a Doctor of Philosophy (Ph.D.) in Educational Research and Evaluation and has 14 years of experience as a chemistry teacher.

The theoretical frameworks of the instructional strategy

This study aims at assisting students can constructing their explanations on redox reaction content particularly. Three theoretical frameworks which are the ground ideas for backing the instructional strategy contain: Firstly, the roles of Vygotsky's (1978)

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internalization process, three steps, still be a structure of the learning process i.e. (1) an external activity is reconstructed and begins to occur internally. This is practically conducted through stage 1: action on macroscopic phenomena by conducting classroom experiments. (2) An interpersonal process is transformed into an intrapersonal one. This is practically conducted through stage 2: learn through classifying three representations including the sharing ideas between groups. (3) the results of transforming an interpersonal process into an intrapersonal one. This occurs as the inner process through prolonged developments rooted in external learning activities and social relations via language and communication. This is practically conducted through stage 3: constructing an explanation via written scaffolding. At this stage, students spend principally time as an individual action through writing and drawing of the claim, evidence, and reasoning resulting from a long series of learning events.

Second is the role of Johnstone's (1991) chemical representations: macroscopic, sub-microscopic, and symbolic. This idea has been trusted as an educational means to assist students in learning chemistry effectively (Taber, 2013a; 2013b; Talanquer, 2011; Gilbert & Treagust, 2009). In addition, many studies are conducted based on this idea in both learners' development (Matijašević, Korolija & Mandić, 2016; Rau, 2015; Adadan, 2014; Philipp, Johnson, & Yezierski, 2014; Dangur, Avargil, Peskin, & Dori, 2014; Lewis & Bodner, 2013; Antonoglou, Charistos, & Sigalas, 2011; Kern, Wood, Roehrig & Nyachwaya, 2010) and teachers' professional development (Taskin, Bernholt, & Parchmann, 2015; Dumon & Mzoughi-Khadhraoui, 2014; Lewthwaite, 2014). In this study, these three content representations have been set for playing a role as the first stage of the instructional strategy because the study of Lin, Son, and Rudd II (2016) found that learning from concrete to abstract is the better way. Participants, therefore, start to learn electrochemistry at macroscopic activities.

The third is the role of the written scaffolding based on two explanation models. The first is the deductive nomological (DN) explanation proposed by Hempel and Oppenheim (1948). This model has often been used as a basis for developing other alternative ideas (Mantazavinos, 2015), such as the explanation model of Tang (2016), Putra & Tang (2016), Fagan (2015). Moreover, it is not only applied in the philosophical study but in science education is also hold such as the studies of Federer, Nehm, Opfer, & Pearl (2015), Braaten & Windschitl (2011), Talanquer (2007), and findings indicate this idea is suitable for students' explaining development. Additionally, Hempel, his name visibly appeared either on the dedication part of philosophical books or the first essay in edited books such as Braithwaite (1955), Salmon (1984), Pitt (1988), Kitcher & Salmon (1989), Fetzer (1993), Ruben (1993), Fetzer (2000), and Rosenberg (2000). Hence, this study focused on this idea in the parts relevant to the learners' explanation ability.

Nevertheless, employing the DN model in the classroom may cause obstacles. The Latin terms in this model may be challenging for students who are not familiar. Furthermore, Scriven (1988) also proposed some limitations and problems of applying DN, which was complicated and more focused on philosophical analysis that was far from the high school classroom. Hence, The Claim-Evidence-Reasoning (CER) explanation model proposed by McNeill (2006) has been focused on because some research findings indicate it is good for improving learners' ability in constructing explanations (Wang, 2015; Thompsom, Braaten, & Windschitl, 2014; Yang & Wang, 2014; Gotwals, Songer, & Bullard, 2009). The CER consists of a *claim* of natural phenomena that learners propose. Then, they have to offer some scientific *evidence* that can advocate that claim, and the *reasoning* is the process that learners should provide to link those evidence to make their claim reasonable. Worksheets as written scaffolding to support students' explaining ability of this study have been designed based on both models.

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All three theoretical frameworks: 1) Vygotsky's internalization process, 2) Johnstone's chemical representations, and 3) DN and CER explanation models have been set as the backing ideas for the instructional strategy of this study as the stages of learning activities.

The stages of the instructional strategy

Stage 1, students experiment with learning macroscopic phenomena of the redox reaction. Students are encouraged to act through hands-on activities that can be seen and touched at this stage.

Stage 2, students learn by expanding the idea from macroscopic to sub-microscopic and symbolic, respectively; in this stage, they were provided the supporting activities to help them learn three chemical representations easier.

Stage 3, they were asked to share their group experiment findings regarding the three levels of chemical representations. This activity is one of Vygotsky's internalization processes. 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.

Stage 4, students were assigned to construct an explanation through a paper-based written scaffolding designed based on the theoretical concepts shaped for this research. In this stage, students were asked to construct an explanation by another question different from the activities of stages 1-3. In this stage, students had learned about the redox reaction between zinc metal and copper (II) sulfate solution during stages 1-3, but during stage 4, they were asked: Which element (between zinc and copper) is the most active oxidizing agent?

Data collection and analysis

Recording data and information during this instructional strategy was conducted as the reflective journal technique in all cycles of the action research. The first author had recorded these classes occurrences as both the journal writing and the journal voice recording in the smartphone. Consulting with the critical reflective peers was recorded as well. Also, students' behaviors during learned electrochemistry have been recorded. All data were analyzed respectively through the process of qualitative analysis as an inductive method, i.e., 1) segmenting, 2) coding, 3) categorizing, and 4) thematizing to make the themes of a phenomenon.

The students' paper-based explanations were analyzed by identifying based on the rubric score, which was made specific to redox reaction contents (see Appendix). This specific rubric score consists of two main elements: major and minor. The major element contains Claim, Evidence, and Reasoning. The minor element contains macroscopic, sub-microscopic, and symbolic representations. The details are shown in the table below.

Table 1: The major and minor elements of rubric score for analyzing the explanation ability, codes, and score for 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

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The Claim is abbreviated as C, and the total score is 2 while the Evidence is abbreviated as E. This Evidence is classified into three sub-types regarding the minor elements of table 1: Macroscopic Evidence: MaE, Sub-microscopic Evidence: SuE, and Symbolic Evidence: SyE. The total score of each sub-type is 3. These three sub-types of Evidence are expected to become the grounded ideas for participants can construct their logical reasoning while Reasoning is abbreviated as R. The macroscopic, sub-microscopic, and symbolic are expected to be merged into an essay of reasoning. The total score of reasoning is 4. If participants can get a full score of explanation ability, the analyzing code of table 1 can be illustrated as 2C-(3Ma-3Su-3Sy)E-4R, which is 15.

3. Findings

This study has avoided declaring students' names and genders because of privacy. So, they all will be called as other codes. For example, a student who is a number 1 of School 1 will be called Sc1No01; likewise, a student who is a number 2 will be called Sc1No02, and others will be called like this pattern, respectively.

Table 2: Categories of students' scientific explanation ability and the frequency of students in each category

Total Score	Categories of students' scientific explanation ability Full = 2C-(3Ma-3Su-3Sy)E-4R	Frequency of students	
		School 1	School 2
15	2C-(3Ma-3Su-3Sy)E-4R	1	
14	2C-(3Ma-3Su-3Sy)E-3R	1	
	2C-(2Ma-3Su-3Sy)E-4R	3	
13	2C-(3Ma-3Su-3Sy)E-2R	2	
12	2C-(3Ma-3Su-3Sy)E-1R	4	
	2C-(3Ma-2Su-3Sy)E-2R	2	7
	2C-(2Ma-2Su-3Sy)E-3R	1	
	2C-(3Ma-1Su-3Sy)E-3R	1	
11	2C-(3Ma-3Su-2Sy)E-1R	2	
	2C-(2Ma-3Su-3Sy)E-1R	1	
	2C-(1Ma-3Su-3Sy)E-2R	1	
	2C-(3Ma-3Su)E-3R		1
10	2C-(3Ma-3Su-1Sy)E-1R	1	
	2C-(2Ma-2Su-3Sy)E-1R	1	
	2C-(3Ma-3Su-1Sy)E-1R	1	
	2C-(2Ma-1Su-3Sy)E-2R	1	
	2C-(1Ma-1Su-3Sy)E-3R	1	
	2C-(2Ma-2Su-1Sy)E-3R	2	
	2C-(3Ma-2Su)E-3R		2
9	2C-(2Ma-2Su-2Sy)E-1R	1	
	2C-(1Ma-2Su-3Sy)E-1R	1	
	2C-(2Ma-1Su-2Sy)E-2R	1	
	2C-(3Ma-3Sy)E-1R	2	
	2C-(3Ma-2Su)E-2R		5
	1C-(2Ma-3Su)E-3R		1
	(3Ma-2Su-2Sy)E-2R		1

Table 2 (Cont.)

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Total Score	Categories of students' scientific explanation ability Full = 2C-(3Ma-3Su-3Sy)E-4R	Frequency of students	
		School 1	School 2
8	2C-(1Ma-1Su-3Sy)E-1R	1	
	2C-(1Su-3Sy)E-2R	1	
	2C-(2Su-2Sy)E-2R	1	
	2C-(1Ma-3Sy)E-2R	1	
	1C-(2Ma-3Su)E-2R		2
	(3Ma-2Su)E-3R		1
7	1C-(2Ma-2Su-1Sy)E-1R		1
	(3Ma-2Su)E-2R		7
	1C-(2Ma-2Su)E-2R		1
6	2C-(1Ma-2Sy)E-1R	1	
	(2Ma-2Su-1Sy)E-1R		1
5	2C-(1Su-1Sy)E-1R	1	
	(1Ma-2Su)E-2R		1
4	2C-(1Ma-1Sy)E	1	
	2C-(2Ma)E	1	
Total	41 categories	39 students	31 students
	(School 1 = 30, School 2 = 14)	Total = 70	

As table 2, there were 41 categories of scientific explanation ability. School 1 had several more categories than school 2. The number of students who got 10 points or more was 36 people (51.43%), more than a half. Nevertheless, only one person could achieve a full score of the explanatory category: 2C-(3Ma-3Su-3Sy)E-4R=15. Therefore, each element would be considered in 4 various facets i.e.

- Interpreting on students who got the same score of a category
- The problems in the Reasoning: an adjusting a written scaffolding worksheet
- Uniqueness of expressing the content representations
- Revising the rubric score

The details were shown below.

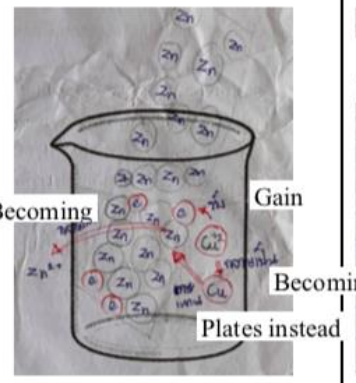
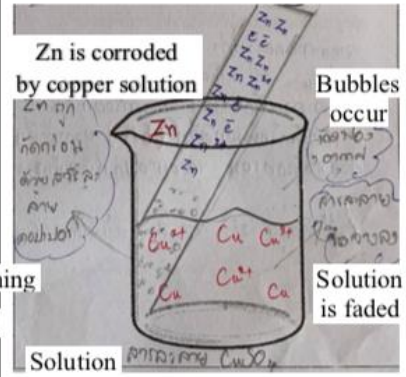
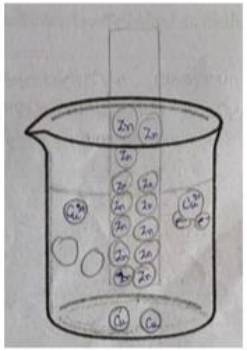
Interpreting on students who got the same score of a category

Considering each score in table 2, we can see the categories. Those several kinds of categories indicate students' differences in each class. The same score might be not the same ability in constructing scientific explanations. For example, at the 11 points of the school 1, there were 4 students different 3 categories. Two people got the same categories but different styles of expressing an explanation. The interpretations of these cases were illustrated in table 3.

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Table 3: Interpretations on the categories of explanation ability of a group of School 1 students who got the same 11 points

2C-(1Ma-3Su-3Sy)E-2R=11	**2C-(2Ma-3Su-3Sy)E-1R=11**	**2C-(3Ma-3Su-2Sy)E-1R=11**	
Student code: Sc1No12	Student code: Sc1No36	Student code: Sc1No32	Student code: Sc1No39
2C S/he made a checkmark at the copper metal's blank which was a correct answer. Therefore, this can be interpreted as the Correct claim (2C).	**2C** S/he made a checkmark at the copper metal's blank which was a correct answer. Therefore, this can be interpreted as the Correct claim (2C).	**2C** S/he made a checkmark at the copper metal's blank which was a correct answer. Therefore, this can be interpreted as the Correct claim (2C).	**2C** S/he made a checkmark at the copper metal's blank which was a correct answer. Therefore, this can be interpreted as the Correct claim (2C).
1MaE  Drawing mode	**2MaE**  Drawing mode	**3MaE**  Drawing mode	**3MaE**  Drawing mode
Written mode *Base on my eyes' observing, I found Zn lost e^- for Cu^{2+}*	Written mode	Written mode *When dipped Zn into $CuSO_4$ solution, Zn metal was*	Written mode *From my eyes observation and experiment, we brought zinc*

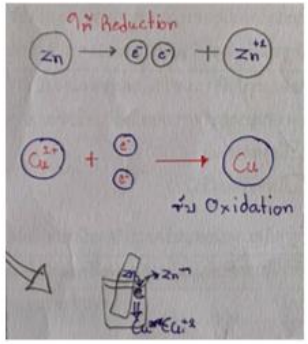
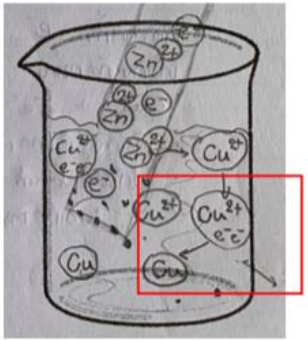
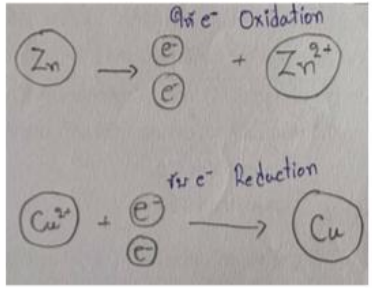
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Table 3 (Cont.)

2C-(1Ma-3Su-3Sy)E-2R=11	2C-(2Ma-3Su-3Sy)E-1R=11	2C-(3Ma-3Su-2Sy)E-1R=11	
Student code: Sc1No12	Student code: Sc1No36	Student code: Sc1No32	Student code: Sc1No39
becoming Cu, resulting in Cu plastered instead. These were the results of my group experiment. Interpretations This student wrote about copper metal plated at something (underline) but s/he was not explicitly stated that it is the thickening of copper metal at the surface of zinc metal which appeared during the classroom experiment. I tried to look for pictures his/her drew but those related to sub-microscopic phenomena. Thus, it was not possible to determine that s/he presented the thickening of copper.	*Cu^{2+}gained e^- from Zn becoming Zn^{2+}. So, Cu^{2+}gain $2e^-$ from Zn becoming Cu.* Interpretations This student did not provide macroscopic phenomena as the direct written mode but wrote as notions in pictures his/her drew. There were two notations could support the claim 1) the corrosion of zinc metal, and 2) the color fading of electrolytic solution (lack of proposing the thickening of copper metal). These, therefore, are determined as the Partially level of macroscopic evidence (2MaE).	*softened and (1)the color of $CuSO_4$ is changed. It could be explained (2)that Zn was softened and corroded because Zn lost e^- becoming Zn^{2+} and color of $CuSO_4$ was changed. And, Cu^{2+} gained e^- becoming Cu (metal). Regarding to the experiment, it pointed that Cu is more ability to gain e^- than Zn. Can be observed by eyes:* - *Bubbles occurred* - *The corrosions of metal* - *Occurring of solid state of (3)red chemical plated at the surface*	*dipped into $CuSO_4$ solution resulting in the change. There were the air bubbles occurred at the surface of metal, and there was (1)the rust plated at zinc metal. For (2)$CuSO_4$ solution have a change, there was the color fading. If we use the stirring rod poked the rust which plated at metal surface, (3)the rust would fall off the metal and corroded.* Interpretations This student could provide all three macroscopic representation as evidence to support the claim (underlines). Therefore, this was the Sufficient level of macroscopic evidence (3MaE).

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Table 3 (Cont.)

2C-(1Ma-3Su-3Sy)E-2R=11	**2C-(2Ma-3Su-3Sy)E-1R=11**	**2C-(3Ma-3Su-2Sy)E-1R=11**	
Student code: Sc1No12	Student code: Sc1No36	Student code: Sc1No32	Student code: Sc1No39
Moreover, s/he lacked the providing of 1) corrosion of the zinc metal and 2) color fading of solution. Therefore, those are only the Alternative level of macroscopic evidence (1MaE).		- *Color fading of solution.* Interpretations This student could provide all three macroscopic representation as evidence to support the claim (underlines). Therefore, this was the Sufficient level of macroscopic evidence (3MaE).	
3SuE  Drawing mode	**3SuE** *The drawing mode was not available* Drawing mode	**3SuE**  Drawing mode	**3SuE**  Drawing mode

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Table 3 (Cont.)

2C-(1Ma-3Su-3Sy)E-2R=11	2C-(2Ma-3Su-3Sy)E-1R=11	2C-(3Ma-3Su-2Sy)E-1R=11	
Student code: Sc1No12	Student code: Sc1No36	Student code: Sc1No32	Student code: Sc1No39
Written mode *"When Cu was dipped into $ZnSO_4$ solution, we found no any occurring, this mean Cu did not lose e^- for Zn^{2+}. It may be indicated that Zn^{2+} cannot gain e^- from copper metal but Cu^{2+} can gain e^- from Zn becoming Cu."* Interpretation S/he stated about the electron transferring from Zn to Cu^{2+} as writing i.e. s/he wrote explicitly that copper (II) ion gained electrons becoming copper metal. So, these evidences can be interpreted as the Sufficient level (3SuE). Moreover, his/her drawing was made to	Written mode *"Cu^{2+} gained electrons from Zn becoming Zn^{2+}. Cu^{2+} gained $2e^-$ becoming Cu."* Interpretation This student expressed the sub-microscopic evidence only the written mode. However, this writing can also represent the electron transferring wholly. So, this can be interpreted as the Sufficient level (3SuE).	Written mode *"Due to Zn lost e^- for Cu^{2+}, Zn became Zn^{2+} and Cu^{2+} gained e^- from Zn became Cu.* *When we dipped Zn into $CuSO_4$ solution, Zn metal was corroded and color of $CuSO_4$ was changed. These could be explained that Zn was soften and corroded because Zn lost e^- becoming Zn^{2+} and color of $CuSO_4$ was changed and Cu^{2+} gained e^- becoming Cu (metal)."* Interpretation This student could write the correct concept about electron transferring. Therefore, this can be	Written mode *"Zn metal was a chemical that lost e^- changing to be Zn^{2+}, and Cu^{2+} gain electrons changing to be Cu that plated at the Zn sheet. When we let the reaction go on and on, Cu metal would occurred plating at the sheet continuously, and Zn sheet would be corroded due to it changed to be Zn^{2+}."* Interpretation S/he stated about the electron transferring from Zn to Cu^{2+} as writing i.e. s/he wrote explicitly that copper (II) ion gained electrons becoming copper metal. So, these evidences can be interpreted as the Sufficient level (3SuE). Moreover, his/her

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Table 3 (Cont.)

2C-(1Ma-3Su-3Sy)E-2R=11	**2C-(2Ma-3Su-3Sy)E-1R=11**	**2C-(3Ma-3Su-2Sy)E-1R=11**	
Student code: Sc1No12	Student code: Sc1No36	Student code: Sc1No32	Student code: Sc1No39
represent the electrons transferring correctly as well. These pictures were exhibited as the pictorial chemical equations of the reduction and oxidation (although, s/he labeled the reaction's names mistakenly).		interpreted as the Sufficient level of sub-microscopic evidence (3SuE). In addition, his/her picture was made to support the electron transferring as well. S/he drew Cu^{2+} gained 2 electrons then became Cu (see the rectangle).	drawing was made to represent the electrons transferring correctly as well. These pictures were exhibited as the pictorial chemical equations of the reduction and oxidation.
3SyE S/he wrote the correct chemical equations of oxidation and reduction reactions. Therefore, these can be interpreted as the Sufficient level of symbolic evidence (3SyE).	**3SyE** S/he wrote the correct chemical equations of oxidation and reduction reactions. Therefore, these can be interpreted as the Sufficient level of symbolic evidence (3SyE).	**2SyE** S/he wrote the reduction reaction correctly, but the oxidation reaction was wrong. Correct reduction: $Cu^{2+}(aq) + 2e^- \rightarrow Cu(s)$ Alternative oxidation: $Zn(s) + 2e^- \rightarrow Zn^{2+}(aq)$ Therefore, these can be interpreted as the Partially	**2SyE** S/he wrote a correct redox reaction but no clarifying about reduction and oxidation which were the key idea of electron transferring in those reactions. Therefore, these can be interpreted as the Partially level of symbolic evidence (2SyE).

Table 3 (Cont.)

2C-(1Ma-3Su-3Sy)E-2R=11	2C-(2Ma-3Su-3Sy)E-1R=11	2C-(3Ma-3Su-2Sy)E-1R=11	
Student code: Sc1No12	Student code: Sc1No36	Student code: Sc1No32	Student code: Sc1No39
		level of symbolic evidence (2SyE).	
2R S/he stated that *"Regarding to the experiment and the evidences from topic 1 and 2, Evidences from topic 1, such we can observed by eyes, Cu^{2+} would gain e^- from Zn becoming Cu. This mean Cu was the electron gainer. Evidences from topic 2, based on the supporting evidence, we found that Cu was also the electron gainer. Hence, these could be concluded that Cu^{2+} gained e^- from Zn becoming Cu which based*	**1R** S/he stated that *"Based on the experiment, when we dipped Zn metal into $CuSO_4$ solution made a change obviously, that was the air bubbles, the color fading of solution, and the corrosions. *Electronegativity (EN) is the number that show the ability to gain electron of pair electrons that make the bond.* *Cu^{2+} magnetized $2e^-$ from Zn becoming Cu.* **Interpretation** This student provided three phenomena of macroscopic evidences, but s/he did not state	**1R** S/he tried to clarify the reasoning by providing two chemical equations. Those equations were made under the alternative idea about the symbol of electrons. S/he wrote that: *$Zn + e^-e^- \rightarrow Zn^{2+}$* *Occurred the e^- losing* *Occurred the corrosion* *$Cu^{2+} + e^-e^- \rightarrow Cu$* *Occurred the e^- gaining* *Occurred the color change* *=>ability to gain more electron*	**1R** S/he stated that *"Based on the experiment, the air bubbles occurred, and there was the dust plated at metal, and $CuSO_4$ solution had a change by color fading. Such the dust that plated at metal, if we used the stirring rod poked, it would fall off to become the sediment.* **Interpretation** This student provided three phenomena of macroscopic evidence, but s/he did not state any sentences to link those evidences to the claim. This reasoning, therefore, was interpreted as the Unacceptable

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Table 3 (Cont.)

2C-(1Ma-3Su-3Sy)E-2R=11	2C-(2Ma-3Su-3Sy)E-1R=11	2C-(3Ma-3Su-2Sy)E-1R=11	
Student code: Sc1No12	Student code: Sc1No36	Student code: Sc1No32	Student code: Sc1No39
on the experiment. Thus, ensuring that Cu is the gainer. Interpretation This student re-concluded that copper was more ability to gain electrons than zinc. S/he provided the electron transfer from zinc to copper as only a written mode which is sub-microscopic evidence (SuE) without macroscopic and symbolic representations. Moreover, those writing could link those evidences to the claim but unclear. This reasoning his/her proposed, therefore, was interpreted as the Developing level of reasoning (2R).	any sentences to link those evidences to the claim. This reasoning, therefore, was interpreted as the Unacceptable level (1R).	**Interpretation** This student provided chemical equation as alternative symbolic evidence, stated some phrases about electrons transferring as sub-microscopic evidences. However, those could not be linked to the claim. This reasoning, therefore, was interpreted as the Unacceptable level (1R).	level (1R).

The problems in the Reasoning: an adjusting a written scaffolding worksheet

Considering the reasoning part of table 2, 4 students could get a full reasoning (4R) score, and only 6 students got a score of 3R. Normally, students are expected to provide the reasoning that links evidence to claim including appropriate and sufficient scientific principles. But most of students could not achieve. It indicated that reasoning still be a problem ability for many students.

To solve this problem, we tried to understand why students could not complete their reasoning even they were good in claim and evidence? Therefore, a student (Sc1No6) who got an explanatory category of 2C-(3Ma-3Su-3Sy)E-2R was focused. Because s/he got merely 2 points of R. His/her worksheet for supporting the ability to construct scientific explanation was shown in figure 1.

This student is a high-performance learner. However, considering his/her works, we found that even s/he could provide sufficient claim and evidence but still encountered difficulty in writing the reasoning. This student wrote the reasoning that "*zinc that was dipped in the beaker of $CuSO_4$ solution had changed, i.e., firstly, the bubbles occur, then the copper metal also occurred because zinc reacted with $Cu^{2+}(SO_4)$ resulting in the electron-donating. When copper gained electrons, copper substituted the zinc position that lost the electrons.*" This essay of reasoning referred to merely 1) a written mode of sub-microscopic evidence that is relevant to electron transfer, and 2) a written mode of macroscopic evidence of the thickening of copper metal, but lack of providing the corrosion of zinc metal and the color fading of copper (II) sulfate solution. Nevertheless, s/he did not refer to symbolic evidence in his/her reasoning. Moreover, his/her reasoning essay could not link those evidence to a claim.

These problems about the explanation of this student accorded to the research of Matijašević, Korolija, & Mandić (2016), which studied students' representation to gas law between pressure and temperature through picture multiple-choice, which they called as an external pictorial representation. Their results showed students still got misconceptions in their explanation, although they answered correctly. These findings were similar to this student who could make a correct claim but could not complete an explanation.

Aside from the worksheet analysis, we also interviewed this student. This interview is expected to elicit some problems from his/her reflective views. The interviewing revealed a barrier that relates to writing methods. It could be illustrated through this dialogue.

First Author: Do you know? You can make good evidences. Why didn't you complete reasoning? It meant you did not bring your good evidence to write reasoning up.

Sc1No06: My reasoning, it is not clear. During I wrote, I could feel that it unclear. But once I already wrote some, I let it go.

First Author can provide good evidences but reasoning…

Sc1No06: I think it still be a conflict.

First Author I saw you help your friends make understandings of magnetic whiteboard activity and others. Did the worksheet instruction in this item make you confused? Or times?

Sc1No06: I….umm.. I just don't know what direction to write. Due to a one is only somethings can be observed by eyes while an another one is equations, if bring it together I don't know how to write. I don't know how to start.

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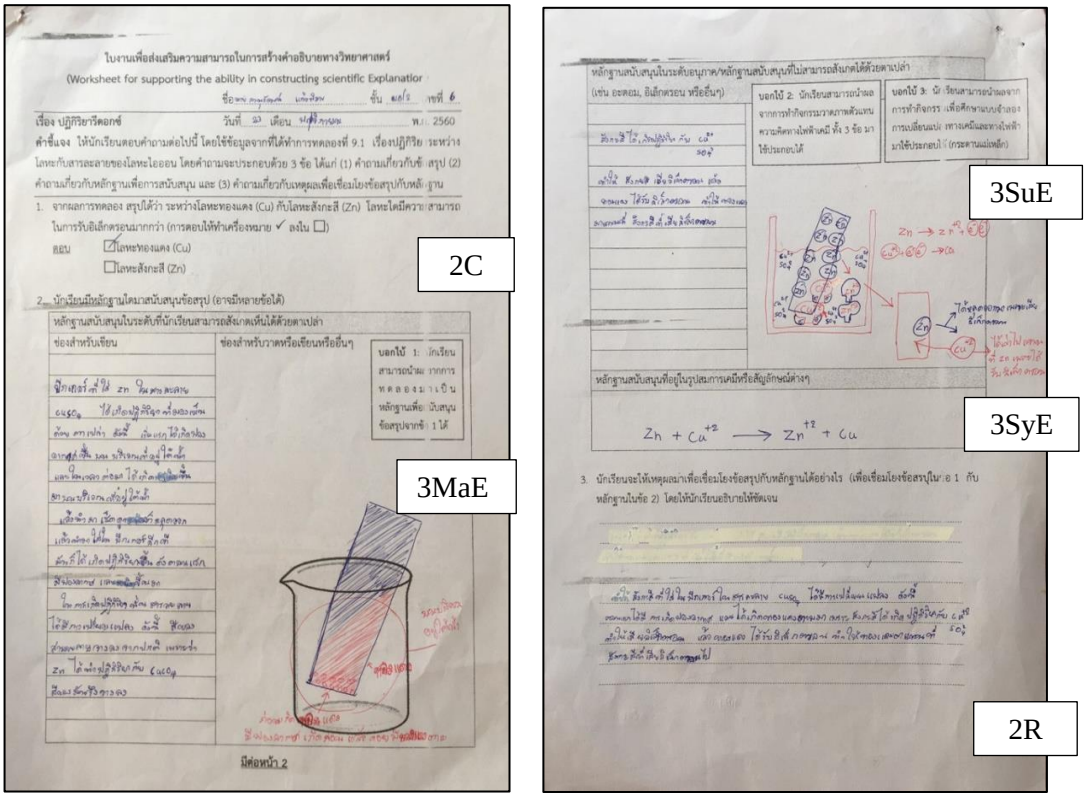


Figure 1: Student's (Sc1No06) worksheet for supporting the ability in constructing scientific explanation who got 2C-(3Ma-3Su-3Sy)E-2R

As the above dialogue, the student reflected a personal problem about beginning his/her writing of reasoning to link evidence to claim. The important problem was the beginning to write. Because we also found that s/he used a correction pen to delete two lines of texts before. It is shown in figure 1, part R. These occurrences indicate the difficulty of the writing method that influences senior high school students' ability to construct a scientific explanation of electrochemistry. Therefore, the first author asked this student more about which parts of this teaching strategy should be improved. S/he suggested that the format of the worksheet should be adjusted. The dialogue about this can be shown below.

First Author: You could provide evidence, but surprisingly your reasoning incomplete. Do you know the reasons of this?
Sc1No06: Yes, I do. I know them.
First Author : How can we solve this problem? This is a problem of this worksheet.
Sc1No06: Yes, at item 3.
First Author : Yes, the reasoning. Could you please help me improve this part?
Sc1No06: I think... We should…. should read….
First Author: Did I write the worksheet instruction is unclear?
Sc1No06: You wrote clearly but don't know which direction to write. Because it is the combination of both (claim and evidence). I think we should write in another paper before by linking them together, or you may divide it.
First Author : Divide?
Sc1No06: Dividing likes you divided at the evidence.
First Author : Ah. You mean the macro, sub-micro, and this symbolic.
Sc1No06: Yes, I think if you do it separately, it may be easier to understand.

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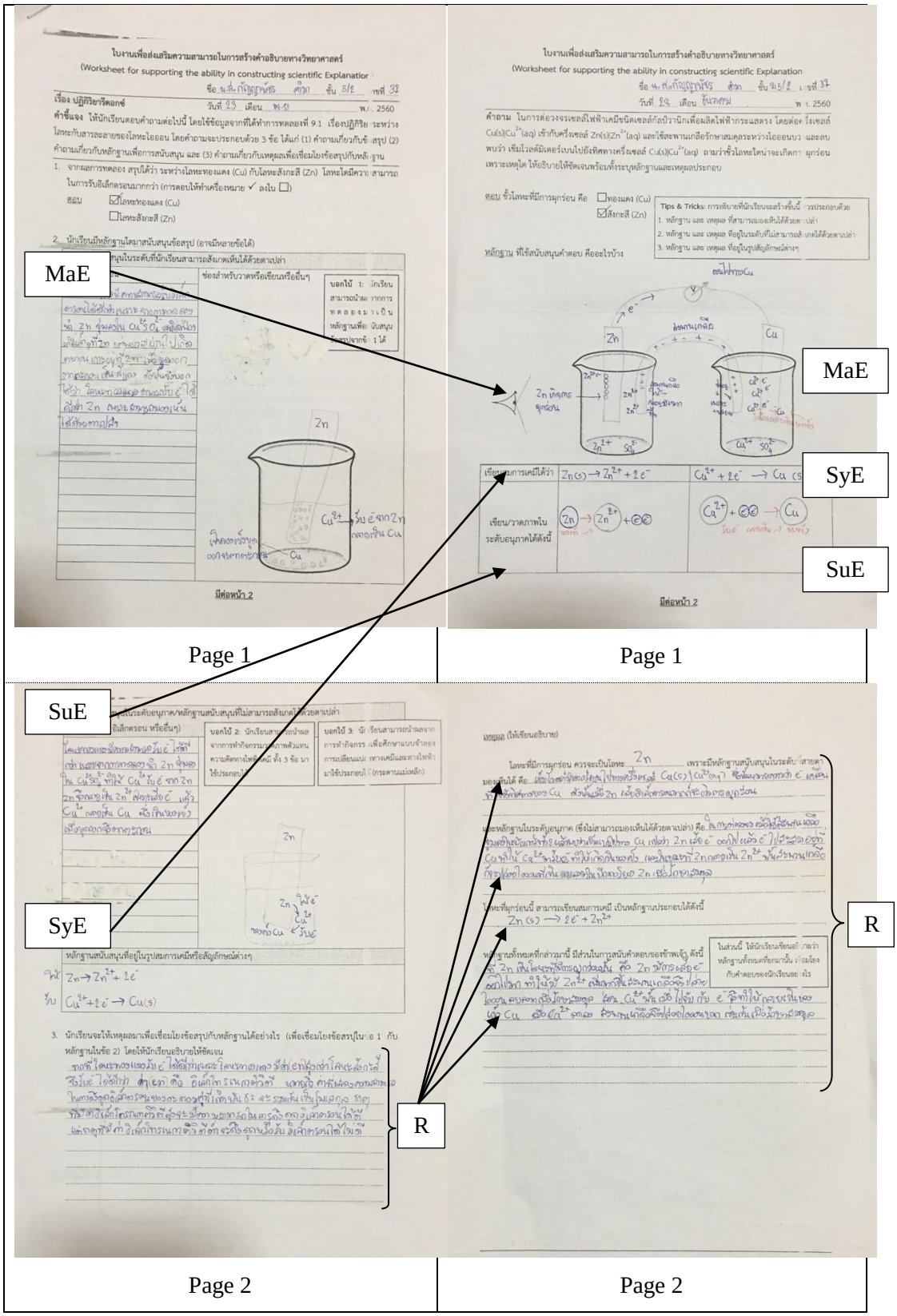


Figure 2: Sample of the worksheet that has been adjusted

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This suggestion is interesting. The worksheet blank of a reasoning part probably has no properties that play a role as assistant tools for students. It might confuse them and become a problem in writing; because we provided only ten blank lines under the worksheet instruction of R, no anything else. Assisting novice students should be done by adjusting a pattern of the worksheet. Researchers, therefore, decided to divide the reasoning blank into three parts: macroscopic, sub-microscopic, and symbolic representations, and one more part for an essay to link claim and evidence. Those are illustrated in figure 2.

Uniqueness of expressing the content representations

Based on the process of reflection, our reflective peer noticed that the students had not recorded the worksheet in a sequence that we had set. Nonetheless, there were not everyone followed this sequence. They learned diverse sequences, i.e., they translated the electrochemistry content into three types. In other words, in stage 2, students are expected to learn three levels of chemical representations by starting from concrete to abstract phenomena; first should be macroscopic, then sub-microscopic and symbolic, respectively. The details of various types of students' expressing are shown in table 4.

Table 4: Frequency and percentage of students classified by the different sequences of expressing representations

Types of sequences	**Type I (Ma-Su-Sy)**	**Type II (Sy-Su-Ma)**	**Type III (Ma-Sy-Su)**
Frequency	34	1	4
(%)	(87.65)	(2.47)	(9.88)

This table shows three types of sequences to translate representations of all 39 students. First is the starting at macroscopic to sub-microscopic to symbolic as 87.65 percent: type I. Second is the starting at symbolic to sub-microscopic to macroscopic as 2.47 percent: type II. The third is the starting at macroscopic to symbolic to sub-microscopic as 9.88 percent (type III). Those diverse ways accord to Gkitzia, Salta, and Tzougraki's (2020) study that found both high school and undergraduate students achieve in various relations to translate representations.

In summary, the reflective peer and authors agreed that it was necessary to improve this worksheet to be more flexible. Therefore, we removed the arrows and the numbers 2 and 3 in the worksheet, retaining only the number 1 at macroscopic representation to point to the beginning stage. This removal is done to support the diverse learning styles of students.

Revising the rubric score

A surprise finding from school 2 was that 11 students (35.48%) had not provided any claim. This phenomenon pointed they did not make a checkmark or anything. It is considered a significant amount compared with the first cycles of action research at school 1 because every student could provide the claim.

Typically, the criteria were designed for the scoring method of the claim as 1 point for a correct answer and a zero point for an alternative answer. Based on some students' failure to provide the claim, the criteria could not work for this school, because the criteria were not designed for the cases of providing anything. Therefore, it is necessary to revise the scoring method of the criteria. The details of this criteria's revising are illustrated in figure 3.

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Initial

Scores	Description
1	Correct claim
0	Alternative claim

Revised

Scores	Description
2	Correct claim
1	Alternative claim
0	No claim

Figure 3: Revising of the scoring method of criteria in the Claim: C

As figure 3, the scoring method was revised. The Correct claim has been adjusted to be 2 points. Likewise, the Alternative claim has been adjusted to be 1 point, and the No claim has been added as a zero score.

4. Conclusions

The critical action research process is the principal method of this study to improve teaching and learning electrochemistry. Action research accepts the flexibility of research methodology, i.e., methods and all educational stuff can be adjusted by targeting the study's objectives rather than keeping the theoretical methods statically.

The rubric score to measure the students' scientific explanations in this study has been revised. Also, the written scaffolding worksheet has been adjusted. Those have been done based on reflecting step of action research, which is the findings from the research fields and varies by contexts.

In addition, implementing the instructional strategy by action research process played a role as a tool to help authors have understood students' learning styles. Several kinds of students' expressing the sequent used of chemical representations are revealed. This can be advantageous for designing the lesson plans for the electrochemistry classroom. Also, the various means to construct explanations of students were considered. Findings revealed that students who got the same score might have different abilities and learning styles. Focusing on students individually is essential for enhancing them to learn.

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Appendix A

Specific Scientific Explanation Rubric for Redox Reaction

Claim

Credit	Level	Answer	Clarification
2	**Correct Claim**	Copper metal (Cu)	Students mark ✓ symbol in the blank ☐
1	**Alternative Claim**	Zinc metal (Zn)	Students mark ✓ symbol in the blank ☐
0	**No Claim**		Not available

Evidence

Credit	Levels	Criteria		
		Macroscopic evidence	Sub-microscopic evidence	Symbolic evidence
3	**Sufficient level of evidences**	Provides 1) corrosion of zinc metal 2) thickening of copper metal 3) colour change (fade) of electrolyte solution: $CuSO_4(aq)$ by writing and/or drawing	Draw atomic/particle level pictures and/or write as notation that show electron transfer from Zn(s) to $Cu^{2+}(aq)$	Write correctly chemical equations of 1) Donating electron of Zn(s) 2) Gaining electron of $Cu^{2+}(aq)$ and describe these two equations
2	**Partial level of evidences**	Provides 1 or 2 appropriate pieces of evidences	Draw and/or write atomic/particle level only donating or only receiving electron	Write only 1 correct chemical equation of electron transfer
1	**Alternative level of evidences**	Provides only inappropriate macroscopic evidences (or non-chemical principle)	Draw and/or write only inappropriate particle level of evidences (or non-chemical principle)	Write alternative chemical equation of electron transfer (or non-chemical principle)
0	**No evidence**	Provides nothing	Provides nothing	Provides nothing

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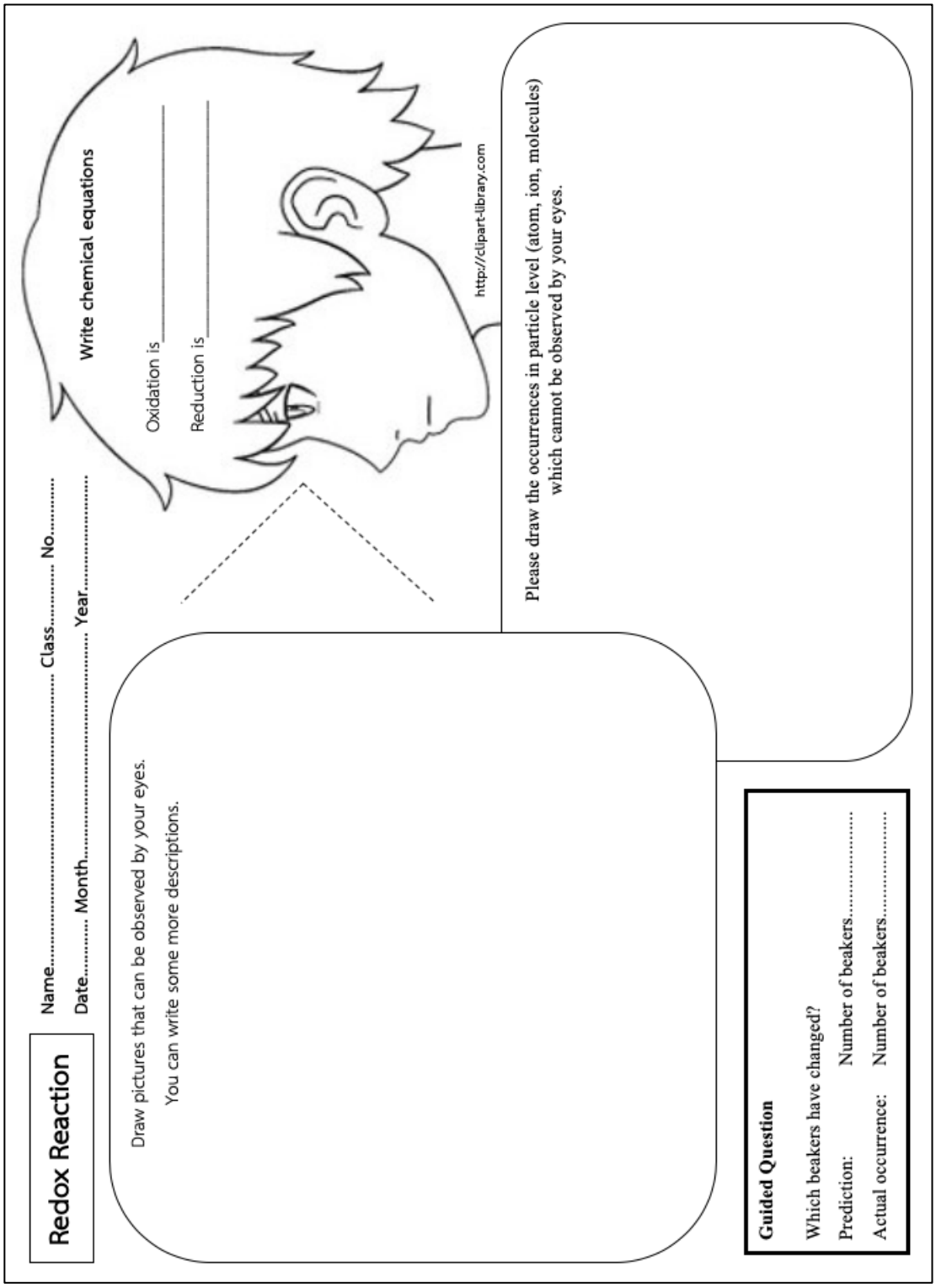
Reasoning

Credit	Levels	Criteria	Clarification
4	**Excellence**	Provides all three chemical representations: macroscopic, sub-microscopic and symbolic evidences link the claim. Includes appropriate and sufficient scientific principles.	Students may only write OR also illustrate pictures which can link chemical evidence to claim. Uses all three evidences support the claim. Can refer classroom laboratory findings to their explanation (provide reasons for linking claim and evidences based on eletrochemical principle)
3	**Good**	Uses 2 of three chemical representational evidences support the claim.	Students provide correct evidences but is not sufficient or do not support the claim
2	**Developing**	Uses 1 of three chemical representational evidences support the claim.	
1	**Unacceptable**	No overall understanding of explanation. No any three chemical representational evidences. Uses alternative evidences support claim.	Students do not provide correct evidences and/or cannot link evidences and claim
0	**No reasoning**	Students do not write or draw anything	

Appendix B

The Writing-Drawing on the Chemical-Electrical Representations Worksheets

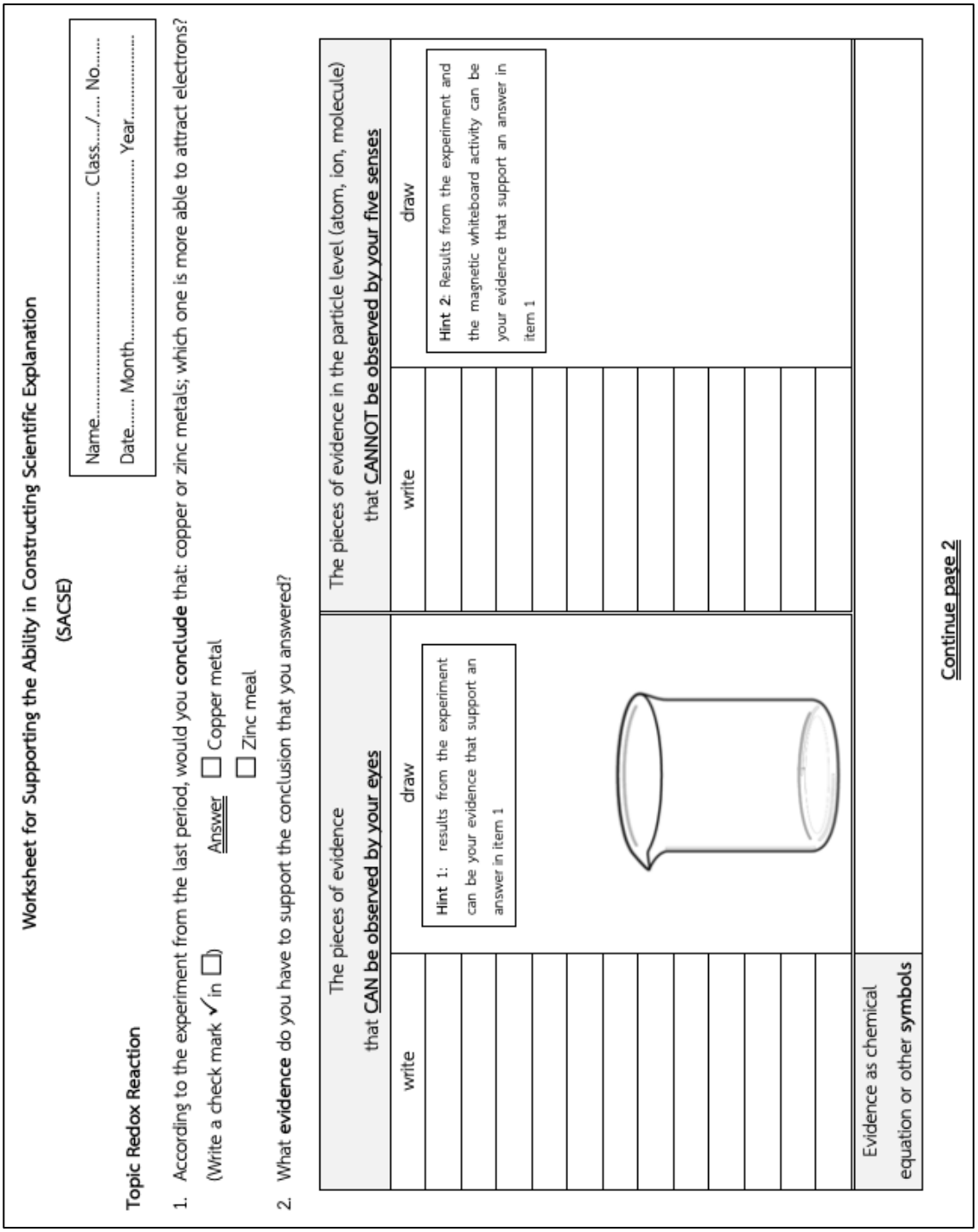
(For Stage 1-2)



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Appendix C
Worksheet for Supporting the Ability in Constructing Scientific Explanation
(For Stage 4)

Page 1



Worksheet for Supporting the Ability in Constructing Scientific Explanation
(SACSE)

Name..... Class..../..... No.....
Date..... Month..... Year.....

Topic Redox Reaction

1. According to the experiment from the last period, would you **conclude** that: copper or zinc metals; which one is more able to attract electrons?
(Write a check mark ✓ in ☐) Answer ☐ Copper metal
☐ Zinc meal
2. What **evidence** do you have to support the conclusion that you answered?

The pieces of evidence that CAN be observed by your eyes		The pieces of evidence in the particle level (atom, ion, molecule) that CANNOT be observed by your five senses	
write	draw	write	draw
	Hint 1: results from the experiment can be your evidence that support an answer in item 1		Hint 2: Results from the experiment and the magnetic whiteboard activity can be your evidence that support an answer in item 1
Evidence as chemical equation or other **symbols**			

Continue page 2

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-2-

3. Please provide **reasons** in order to link your conclusion in item 1 with evidence in item 2. Please explain explicitly.

Which kind of metal that more ability to attract electrons?

Answer ...Copper./..Zinc....;

Because there is supporting evidence that can be observed by eyes.....

.....

.....

.....

.....

Supporting evidence in particle level.....

.....

.....

.....

.....

.....

.....

Supporting evidence in symbolic level (chemical equations) .....

.....

.....

.....

How all three types of evidence can support your answer/conclusion about the ability to contract electrons?

.....

.....

.....

.....

Hint 3:

Students should provide reasons to link your conclusion in item 1 and three types of evidence in item 2

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