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# Advancing Conceptual Understanding of Science

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**Abstract.** Categorisation of the entities of the world are important to help one make sense of the world and this process forms an integral part in the development of concepts. Inadequate clarifications and understanding of concepts in science may result in difficulties in the learning of science. In this paper, the authors discuss what the term, 'conceptual understanding', entails in the learning of science, using examples from the topics of 'Acids and Bases' and the 'Particulate Nature of Matter'. The authors also provide suggestions on how teachers can teach for conceptual understanding in the classroom as well as in the laboratory.

**Keywords:** conceptual understanding, acids and bases, volume of gases, practical work, modelling

## 1. Introduction

When a mother wants to teach her young daughter what a fish is, usually she will show the girl a live fish if she has access to an aquarium or a pond, or a whole fish from her refrigerator, in the supermarket or at a fishmonger's stall. Most likely, the mother will point out the fins, gills and scales of a fish, and inform the girl that fishes live in water. During formal lessons, the girl also will be taught that fishes are vertebrates and cold-blooded. These attributes that the girl learns will enable the girl to differentiate fish from other creatures that live in water, for example, crab, turtle, prawn, squid and jellyfish (even though there is 'fish' in the term 'jellyfish'). However, she may be bewildered and have difficulties identifying the stingray and mudskipper as fish because their appearances are so unlike a typical fish. She may also wonder why dolphins and whales are not considered as fishes when they look so much like a fish.

A family of four was travelling in a car. The father was driving and after a while he felt thirsty. He asked his wife to hand a bottle of water to him. When he was about to take a sip of water, his son, sitting in the back seat of the car, suddenly jumped up and grabbed his hand which was holding the water bottle. Due to surprise and the action of the boy grabbing his hand, the father swerved the car and it almost went into a ditch at the side of the road. He turned to the boy angrily and asked the boy why he grabbed his hand. The boy tearfully replied that he saw a sign in a restaurant earlier which read, "Don't drink and drive", so he wanted to stop his father from doing so. Although the boy understood the literal meaning of the sign, he has little awareness of its contextual meaning, giving rise to his unfortunate action in the car.

## 2. Understanding concepts

Herron (1996) defines a concept as a set of objects, symbols or events grouped together based on shared characteristics and referenced by a particular label. Novak (2002) defines concepts in a similar manner – concepts are "perceived regularities in events or objects, or records of events or objects designated by a label" (p. 550). In order to explain or clarify a concept, one has to be able to identify its critical attributes (must be present) and variable attributes (need not be present), and give examples and non-examples of it. The critical attributes of a fish are that it is a vertebrate which has gills, scales and fins. Variable attributes of a fish include its shape, size, appearance and habitat. Thus goldfish, tuna, salmon and stingray are all considered as examples of fish as they have the critical attributes of a fish; a mudskipper is also considered a fish based on the critical attributes even though its bodily adaptations allow it to live out of the water. On the other hand, whales do not have gills or scales, so they are considered as non-examples of fish. J. K. Gilbert (personal communication, June 30, 2016) suggests that learning the critical attributes of a concept reduces the cognitive load presented by individual facts (e.g., characteristics of the different types of fish) and highlights the relationship between instances of the concept in apparently different contexts (e.g., mudskipper, stingray, goldfish).

## 3. Acids and bases

When a chemistry teacher asks her students what an acid is, she will most likely get these answers from the students:

- It turns blue litmus red
- It has a pH of less than 7
- It has a sour taste
- It reacts with a reactive metal to produce a salt and hydrogen
- It reacts with a base to produce salt and water
- It reacts with a carbonate to produce salt, water and carbon dioxide

The answers given by the students describe the properties of an acid but do not explain what an acid is. In addition, what an acid is depends on what model one is using to explain what it is. Using the Arrhenius model, which is the model commonly used in Grades 7 to 10 chemistry in Singapore, an acid is a substance which produces hydrogen ions in aqueous solution. This is a critical attribute of an acid as the hydrogen ions produced are responsible for the properties and reactions of acids. For example, calculation of pH involves the hydrogen ion concentration of the acid, and it is the hydrogen ions that will react with the bases and metals, as well as the dyes in indicators to cause colour changes. There are many examples of acids, and these include hydrochloric acid, sulfuric acid, ethanoic acid and phosphoric acid. These acids have different variable attributes such as containing different elements and number of atoms, as well as having different strengths and proticities. On the other hand, using the Arrhenius model, methane, potassium chloride and sodium hydroxide are considered to be non-examples of acids because they do not have the critical attribute of producing hydrogen ions in solution. There is a need to compare and contrast examples and non-examples to bring out, more explicitly, the critical and variable attributes, and this should facilitate better understanding of a concept; when a student understands a concept, he/she will have little difficulty in differentiating between examples and non-examples of the concept (Herron, 1996). This is also supported by variation theory which proposes that teachers help students to focus on critical features of concepts and to contrast between examples and non-examples to make sense of the concepts that the students are learning (Bussey, Orgill, & Crippen, 2013).

A base in the Arrhenius model is one which produces hydroxide ions in solution. Thus, sodium carbonate is not considered as a base when the Arrhenius model (unless another concept, hydrolysis, is introduced) but the carbonate ion can be considered as a base if the Lowry-Bronsted model is applied; bases are proton acceptors and the carbonate ion can accept a proton to produce the hydrogencarbonate ion. Thus, the critical attribute of a concept depends on the model used, so using different models can result in different critical attributes, and hence, different examples and non-examples of the concept. A more 'powerful' model will usually subsume the examples and non-examples of a less 'powerful' model but, as shown in the example of sodium carbonate, it may not be true the other way round. Therefore, it is not surprising students find the topic of acids and bases difficult due to the confusion over the models that are used in teaching the topic (Carr, 1984; Schmidt, 1991) especially if the use of the different models is not "carefully sign-posted" (Carr, 1984, p. 99) by teachers or textbooks.

If the chemistry teacher asks her students what they need to do if they accidentally splashed some hydrochloric acid into their eyes, a possible response will be to wash the eyes with sodium hydroxide to 'neutralize' the acid (Schmidt, 1991); this response is logical given what the students learn about neutralization reaction in which an alkali reacts with an acid to give a salt and water. However, the students may not realise that sodium hydroxide is also corrosive and harmful (Nakhleh & Krajcik, 1994). In addition, the heat liberated in the neutralization reaction may cause further damage to the eye. Thus, the best solution is to wash the eye with copious amounts of water to dilute the acid and flush it from the eye. However, if acid was spilled on a road by an overturned tanker, what would be the best way to removing the acid? In this case, using water to remove the acid from the road may not be an effective solution as the acidic waste water may pollute the immediate surroundings. The acid should be neutralized but a soluble base cannot be used because it is almost impossible to determine how much of the base should be used; if too much soluble base is used, the excess base will now be the environmental problem, while if too little of it is used, the acid will not be removed. A relatively insoluble base such as oxides, hydroxides or carbonates of calcium can be used; after neutralizing the spilled acid, the excess insoluble base can be swept up and removed with relatively minimal impact on the environment. Thus, application of one's knowledge requires more than the understanding of a particular concept, it requires understanding of concepts in relation to other concepts which are linked to them and the context of the situation (Novak, 2002). This applies to the boy in the car who understands the literal meaning of "Don't drink and drive" but may not realise that the 'drink' refers to the imbibing of alcohol before or during driving which may impair one's driving ability rather the drinking of water when driving. It has to be mentioned, though, that the act of drinking water while driving may actually pose a hazard as the driver may not be concentrating fully on the road while drinking. Thus, there can be more than one level of conceptual understanding involved in a situation.

The student is responsible for his/her learning (Novak, 1988) as he/she has to decide that he/she wants to learn and make sense of the learning task (Ausubel, 1968). Teachers are often questioned, "so what" or "for what", by students when they are required to learn concepts that seem to be meaningless and/or have no apparent relevance to their everyday lives. Gee (2007) puts it succinctly:

One good way to make people look stupid is to ask them to learn and think in terms of words and abstractions that they cannot connect in any useful way to images or situations in their embodied experiences in the world. Unfortunately, we regularly do this in schools. (p. 72)

Students need to know the reasons for learning what they are taught and how it is useful to them, as well as to be given opportunities to practice or use the knowledge that they are learning in meaningful ways. If the students find what is taught by the teacher meaningless, "useless" or "stupid", they may not want to learn it at all or find it difficult to learn; they need "meaningful, goal-driven contexts" (Gee, 2007, p. 65).

Learning what acids are and the properties and reactions of acids in isolation may seem to be pointless to students. However, learning these in the context of a competition in which they have to build a gas-propelled rocket which can fly the furthest distance may make the learning of the reactions of acid (and kinematics) more interesting. Students will need to learn which reactions will produce gases and how reactions can be speeded up. Stoichiometry can be involved as well as the students might want to calculate the masses of reagents required and the volume of gas liberated, and they have a reason for doing; this is a contrast to the contextless problems that they are given to solve in class. It may also be interesting to get students to brush their teeth and then give them orange, lemon or lime juice to drink; this is something which the students may have encountered when they drink orange juice at breakfast. Most of them will find that the juice tastes terrible and they can be tasked to find out why. They can also be instructed to remove certain stains using material commonly found at home, for example, lemon juice, vinegar and baking soda, and find out why these work well as household cleaners. In these ways, students can experience science learning in a way which is meaningful and situated, and they can use the knowledge to solve problems (Gee, 2007) instead of merely studying to pass examinations.

## 4. Volume of gases

Students in Singapore learn the properties of solids, liquids and gas at the primary level (Ministry of Education, Singapore, 2013), for example, they learn that gases have no fixed volume and no fixed shape. In lower secondary (age 13-14), they learn that the behaviour of the particles in a gas is responsible for the properties of the gas (Ministry of Education, Singapore, 2020) and in upper secondary (age 15-17), they are taught that molar quantities of gases have a volume of 24 dm3 at room temperature and pressure in their chemistry lessons (Ministry of Education, Singapore, & University of Cambridge Local Examination Syndicate, 2021). In the authors' years of teaching in school and in a teacher education institution, nobody has ever pointed out the apparent contradiction between the fact that 'a (mole of) gas has no fixed volume' and that 'a mole of gas has a volume of 24 dm3 at room temperature and pressure', leading the authors to believe that the students and pre-service teachers merely accepted them as facts that they have to learn, with no further need to probe what they mean or the contexts in which they apply. According to the particulate nature of matter, an ideal gas will tend to spread outwards if not confined by a container, or occupy the volume of its container if confined in the container, as it consists of "particles that do not exert long-range forces and that move in straight lines until they collide with the container walls or other particles" (Robertson & Shaffer, 2013, p. 303). However, if a gas is liberated in a reaction involving known amounts of reactants and made to flow into a syringe with the plunger depressed under the conditions of room temperature and pressure, the gas will push against the plunger and move it outwards until the pressure of the gas in the syringe is equal to the atmospheric pressure acting on the plunger. When the plunger stops moving, the gas liberated will occupy a volume indicated on the marking of the syringe. This volume will be less than the calculated volume of the gas liberated as the gas has to work against the friction between the plunger and the walls of the syringe. Most of the trainee teachers that the authors taught only realized the significance of the different contexts involved when they were asked to design an experiment to determine the volume of a gas at room temperature and pressure; otherwise, the conditions of room temperature and pressure had little meaning to them.

Interestingly, Robertson & Shaffer (2013) reported that the undergraduates and K-12 teachers in their study also had difficulties with volume of a gas and the behaviour of the particles in the gas, this time in the context of being confined in rigid containers under the conditions of different temperatures. They found that many participants thought that the volume of a gas decreases with decreasing temperature such that it had a volume different from that of its container because the particles in the gas had more limited movement as they slowed down and hence occupied a smaller volume by gathering in the centre of the container. Thus, it seems that teachers and students need to clarify the behaviour of the particles in gas, and hence the volume of the gas, at varying temperatures in different contexts, for example, in an open environment, constrained in a syringe or in a rigid container.

## 5. Understanding practical work

Generally, students spend a significant portion of the science curriculum time doing practical work where they handle equipment and material to perform experiments ranging from those which are supposed to help them to understand the science concepts taught in the classroom to investigations which address real life problems (Hofstein, Kipnis, & Abrahams, 2013). In addition to helping students to learn science, practical work has the potential to facilitate the acquisition of process skills and scientific habits of mind, as well as the development of positive attitudes towards science (Hodson, 2005; Hofstein, 2004; Hofstein, Kipnis, & Abrahams, 2013; Nakhleh, Polles, & Malina, 2002). However much of the practical work done in school seems to be recipe-driven and undemanding, emphasising mainly on the manipulation of equipment and getting the 'right' answer (Crawford, 2000; Hoftstein et al., 2013; McNally, 2006). Students tend to have little conceptual understanding of what they do during practical work and may not be able to engage meaningfully in it (Hart, Mulhall, Berry, Loughran, & Gunstone, 2000; Sere, 2002); they simply follow the instructions given to them, assemble the required apparatus without knowing why the apparatus and procedures are necessary for the experiment, and make the required observations without understanding what the observations mean (Gunstone, 1991; Sere, 2002; Tasker & Freyberg, 1985). Doing experiments incorrectly may result in safety hazards and/or wastage of reagents, so students normally learn or carry out the 'correct' procedures without being required to think of alternative procedures or why a procedure is 'correct' or more suitable for a particular purpose than alternative procedures (Tan & Chee, 2014). For example, to separate an insoluble solid from a liquid, filtration is normally used but distillation can also be used; however distillation is more time consuming, the experimental setup requires more effort and apparatus than filtration, and there may be safety issues arising from the heating in the distillation process. Unfortunately, students are seldom asked to ponder on the procedures that they carry out in the laboratory.

In a study (Tan, 2020) by the first-named author to determine how intermediaries can facilitate teachers' use of research to address student difficulties (Ratcliffe et al., 2004), teachers from a high school (Grades 11 and 12) whom the first-named author worked with chose to address the issue of student difficulty in planning experiments. To determine if student difficulty in planning experiment was widespread, teachers from five schools and a curriculum development branch were surveyed. All 28 participating teachers agreed that students had difficulties planning experiments. One of the main reasons for the difficulties proposed by the teachers was that students did not have enough knowledge of experimental procedures, reagents and apparatus. About half of the teachers believed that this could be due to the lack of opportunities to do a wide variety of experiments apart from those required for the national assessment, a lack of understanding of procedures, or following procedures without thinking about them. The teachers' comments on the students' difficulty in planning experiments agree with the findings of studies on practical work (Hart et al., 2000; Gunstone, 1991; Sere, 2002; Tasker & Freyberg, 1985) discussed in the previous paragraph.

Woolnough and Allsop (1985) have suggested that practical work should focus separately on allowing students to experience and understanding the phenomena and reactions involved in the experiments that they do, developing the skills and techniques to carry out experimental procedures effectively, and conducting investigations to experience how a scientist works. The separate objectives are intended to avoid overloading the working memory of students during practical work (Johnstone & Wham, 1982) as little learning can occur if students are concentrating mainly on carrying out the procedures given, and collecting and recording data within the time constraints of the laboratory session. Tan, Goh, Chia and Treagust (2002) developed an instructional package on qualitative analysis based on the principles proposed by Woolnough and Allsop (1985). The first focus of the instructional package was on helping students to experience and understand the reactions underlying the tests for cations, anions and gases; they had to relate their observations to what they had already learned in the topic of 'Acids, Bases and Salts'. Next the 'exercises' were introduced where the students would practice the required procedures step-by-step until they were proficient in these procedures; students needed to master these skills and perform them 'automatically' to lower the demands on their working memories so that they could attend to other aspects of the experiment (Woolnough & Allsop, 1985). Finally, students would apply their knowledge and skills to design and implement investigations to identify the unknown ions present in given samples. It was found that the students who were taught using the instructional package had a better understanding of qualitative analysis than the other students who were surveyed in the study.

## 6. Beyond practical work: Advancing conceptual understanding through modelling

Practical work allows students to experience the phenomena associated with the concepts learned, hence convincing students of the scientific ideas and addressing any alternative conceptions they might hold. Thus, experiments are useful for producing evidences to demonstrate macroscopic relationships (e.g., gases occupying the same volume despite a lowering of temperature will exert a lower pressure in a fixed container), convincing students to reconsider any misconceptions they might possess. However, practical work might not directly address developing conceptualisation related to causal explanations. For example, practical work cannot demonstrate the causal mechanism underlying the relationship amongst temperature, volume and pressure of a gas. In high school chemistry, such causal explanations often draw upon concepts visualised at the microscopic or sub-microscopic levels (Johnstone, 1982) and involve the use of scientific theories and models to construct the explanations. To advance conceptual understanding developed to include causal explanations, we propose the use of a representation-construction pedagogy, Image-to-Writing (I2W) (Yeo, Lim, Tan, & Ong, 2021), to complement experimentation in the learning of chemistry and thus extend learning towards the construction of causal explanations.

The I2W approach comprises three main stages: (1) exploring a phenomenon, (2) creating and transformation of images and (3) translation of images to writing. Through these stages, students are engaged in constructing and working with visual representations in their conceptualisation of a scientific idea before writing them down in formal scientific language. The I2W approach is modelled after the visualisation practices of scientists as they go about theory buildings (Gooding, 2004; Nersesian, 1992). Yeo and Gilbert (2014; 2022) also found that high school students often make use images with other modes of representations as they go about producing causal explanations in physics, including those related to the particulate theory of gases. The design of I2W learning process is anchored by a key question about a physical phenomenon that provides purpose for the visualisation activity and can be used in conjunction with practical work. Students are often engaged in making observations of phenomena and hands-on experiments. They create a series of images to represent their observations and meanings made about the phenomena and to use these images to help them think and reason about the relationships between related concepts. Writing in formal scientific language, which is often the expected form of output in school science learning, comes at the end of the process when students have developed a narrative account of how or why a phenomenon comes about.

To illustrate how I2W can be applied to advancing conceptual understanding of chemistry, let us consider its use in addressing students' conception that gases would occupy a smaller volume when temperature is decreased. The activity could start with demonstration (using video or simulation) of the macroscopic phenomenon whereby volume, temperature and pressure of the gas in a thick-walled container can be measured as temperature of the gas is decreased. With the available data and the premises from the kinetic theory of gases, students could be engaged in constructing a series of images to illustrate the behavior of the particles of gas as temperature decreases. They can also produce animations of the constructed images to develop a narration (causal explanation) so as to account for the observed macroscopic properties of the gas (Berg, Orraryd, Pettersson, & Hulten, 2019). These visuals and narration produced by the students can allow the teacher and their peers to identify any misconceptions students might have with the kinetic theory of gases as well as its application. This is because, compared to words, visuals are more effective in making clear the meaning of processes, topography and temporality, which are the key ideas underlying the kinetic theory of gas.

## 7. Conclusion

Conceptual understanding entails knowing the critical and variable attributes of the concept, and the ability to apply the critical and variable attributes to decide examples and non-examples of the concept. If abstract concepts are involved, students need opportunities to develop visual representations of these concepts to make sense of them. The contexts in which concepts are applied are also important and students need to have opportunities to apply what they have learnt in various situations to realise the affordances and limitations of concepts, as well as the value of learning these concepts. In a similar vein, students also need to be exposed to situations where there is no one correct answer but several alternative solutions and the need to evaluate these alternatives to choose the best among them for the particular situation. Practical work is important in science for students to be exposed to and understand these phenomena, as well as develop the thinking, skills and techniques to conduct investigations. However, the activities that students do need to be carefully thought out to prevent cognitive overloading, leading to mere manipulation of equipment and minimal learning.

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# Borsang Umbrella Handicraft: A Science Learning Resource in Thailand

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**Abstract.** "Borsang's umbrella making" is indigenous knowledge of Science in San Kamphaeng District, Chiang Mai, Thailand. This local knowledge has been relevant to culture and traditions that are important products exported from the past to the present. This qualitative study aimed to survey its manufacturing process and immersed scientific concepts linked to the Thai National Science Curriculum Standards. Data were collected through participant observations and in-depth interviews. The participants were seven folk philosophers who made a career with the Borsang umbrella making, and the data were analyzed with content analysis as the inductive analysis. Also, the data reliability was verified by member check, peer reviewers, and triangulation method. As result, the findings indicated that the process of "Borsang umbrella-making" included 4 steps 1) material preparation for the canopy 2) building an umbrella structure 3) sealing the canopy with the structure, and 4) Painting and dyeing. Along the process, the scientific concepts found for the Borsang umbrella-making were properties of materials, physical and chemical properties of matter, and polymer. As a recommendation use of the indigenous knowledge as a science learning resource for Thai students, needs to concern organizing this kind of knowledge to fit into the National Science Curriculum and preparing science teachers to be ready and aware of its implementation in school contexts.

**Keywords:** Borsang, Science Learning, Indigenous knowledge, Local wisdom, Thailand

## 1. Introduction

Local wisdom (Indigenous Knowledge) is the knowledge that people in the community discovered by faith and behavior modification depending on the experience of adjusting to life and their local environment taking into account the social context, arts, culture, and way of life are main [1]. The interaction with the environment in the community has been developed over a long period. Local wisdom affects the complexity of community culture, resources, and social interactions through the perception of people in the community. From the potential development of local knowledge development to uplift the grassroots economy of the community through the cooperation of members within the community. Following the policy to reduce inequality generates income and prosperity economic strength by adopting the sufficiency economy as a framework for community practice [2] in which the use of local wisdom skills and geosocial readiness in that community seeking knowledge of local wisdom which take Its part of the scientific process. This is because indigenous wisdom is a process that explains science through culture. By starting from the process of people in the community, the process of rational observation classifies natural events and solves problems arising from the process of

local wisdom. [1] Local wisdom is also developed and applied knowledge through the scientific process. Either as a hypothesis test experimental use and solving problems related to solving local problems and it can be said that local wisdom is a body of knowledge that is consistent with the nature of science that consists of the scientific world view, scientific Inquiry, and the scientific enterprise. [3]

At present, local wisdom is also classified as an important source of scientific knowledge. According to the core curriculum of science learning subjects, revised edition (2017) [4], which has defined indicators and core learning subjects that students need to learn and appreciate science through local wisdom to be used as a basis for living or continuing education which requires learners after graduating from Mathayom 6 must "recognize the importance and value of science and technology knowledge used in daily life, apply the knowledge and processes of science and technology to life and occupation. Moreover, learners could show appreciation, pride, praise, reference work, works that are the result of local wisdom, and modern technology development. Learners can learn more, do projects, or create pieces according to their interests. "It can be seen that the core curriculum (revised edition 2017) focuses on enabling learners to develop works derived from local wisdom. and able to develop the potential to develop as a career path in the future.

Management of science learning that integrates local wisdom, is an alternative learning management approach that helps learners learn effectively in each context. Making science learning that integrates local wisdom in science classrooms is a learning management approach that allows learners to access the knowledge of local wisdom. Understand the worldviews and approaches of different bodies of knowledge in each locality[5] Make a learning management approach for science teachers who want to teach science by integrating local wisdom with lessons. A variety of concepts and classroom experiences need to be organized. as well as a variety of scientific concepts in teaching and learning design to connect learners with their contexts. Therefore, development guidelines for science teachers Management of science learning that integrates local wisdom, Therefore, it is important to develop students' potential by the goals of the curriculum and society in the future.

Developing science teachers is the key to developing learners. But at present, it is found that the development of science teachers to manage learning that integrates local wisdom is not supported as it should be. Because the traditional teacher development believed that local wisdom knowledge is a body of knowledge that is not in line with scientific knowledge.[6] Therefore, in the development of science teachers to develop science learning management that integrates local wisdom. The researcher, therefore, studied the development of science learning centers in Thailand as a study of umbrella-making handicrafts of BorSang District, Chiang Mai Province which is the local wisdom of Chiang Mai that reflects the culture and the image of tourism and is a product that is classified as one of the outstanding export products of Chiang Mai.

## 2. Methodology

local wisdom in Chiang Mai mostIt is a business about agricultural products and also outstanding in bringing local wisdom about local arts and culture because the charming old town boasts of diverse local cultures and languages, such as food, traditional architecture, festivals, handicrafts, and uniquely beautiful dances. There are also hill tribes that have different and unique cultures, making them stand out and adding diversity to Chiang Mai. The researcher selected to study local wisdom in handicrafts. In "Making an Umbrella" of the BorSang community in San Kamphaeng District, Chiang Mai Province. By collecting data from 7 research participants who are qualified to choose the location of the data collection. Handicraft center umbrella-making center is a popular learning center and allows outside to study the process of making umbrellas that is unique to the community. The criteria for selection must be people who work within the handicraft center who are professionals within the center for not fewer than10 years and are voluntary in providing information and in collecting data, village sages had to perform umbrella activities throughout the data collection.

The researcher visited the center's area to make participant observations by keeping records of events, words, and actions of those involved in the center. The researcher has been visiting the area for some time (1 week) to get acquainted with the person on the premises and a preliminary understanding of the body of knowledge and local wisdom. The researcher then took the results of the records of events, words, and actions of those involved and interpreted them from the field notes. Examples of field recordings "The selling place consists of the sale of the center's products. At the entrance, there is a sale of color--related products used for drawing patterns on umbrellas. In the other zone, various products that are souvenirs of Chiang Mai will be sold, such as wood carvings, silver jewelry, and a shirt pin, which is a distinctive product of Chiang Mai's local wisdom. Later, there will be products related to fans and umbrellas. which are divided into 4 zones, in zone I, It is an umbrella made of cotton. Where Zone II, is an umbrella made of mulberry paper. In Both zones, I and II umbrellas are available that are painted and finished patterns and are a solid color. For customers who want to draw a product's specifics, that zone III, which about products that use mulberry paper such as mulberry paper lanterns, and mulberry paper mobiles. In Zone IV, it will be a product about decorative items such as fans and there also has a zone that tells the story of the local wisdom of the BorSang community in umbrella making and lifestyle as well. Moreover, there is an exit door to study the process of making umbrellas. There will be a walk to see the products around the distribution area and then continue to walk out to the place to see the process of making umbrellas and will come back to buy products according to the patterns or characteristics that customers like. Some people will have to buy in solid colors. Then hire a local sage to draw patterns or design according to their needs, then, brought all the data obtained as the results of the observations to create the next tool is a semi--structured interview. Analysis of the results of participant observations then analyzes the content with the analysis steps. The researcher read all the information obtained and extracted the data as segmenting. After all, the collected data was divided into 6 issues as follows: 1. The identity of the umbrella 2. Handicraft center 3. Guidelines for the transmission of wisdom 4. materials and equipment for making umbrellas 5. Methods of making Umbrella and 6. Knowledge development of local wisdom (category) and then coding the information. After the researcher considered all messages for encoding, the example is detailed in Table 1, then the researcher made a codebook.

**Table 1** shows an example of a content analysis from Participatory observation 5. Umbrella-making method and 6. Knowledge development of local wisdom.

| **field record form** | **Category** | **code** | **message** |
|---|---|---|---|
| How to make an umbrella? | | | |
| date1 | location | Lo1 | When entering the San Kamphaeng district, it is decorated with umbrellas. And there are shops selling umbrellas between both sides of the road. |
| date1 | | Lo2 | Area in front of the center, there are photo spots, cafes, and gardens where you can sit and relax under the big trees. |
| date3 | | Lo3 | When tourists arrive and park their cars, will walk into the inner area, then walk straight into the area that makes the umbrella behind and go back to buy products inside |
| date1 | product | P1 | Products related to arts and culture, whether postcards, mobile from mulberry paper, carved wood, or carved silverware. |
| date2 | | P2 | The umbrellas that are sold are divided into 2 groups, a group that has already painted patterns and colors and a group that has been painted without drawing patterns. |
| date1 | product position | LP1 | Zone I is an umbrella made of cotton. Zone II is an umbrella made of mulberry paper. Where zone III was about products that are |
| | | | recycled paper. Zone IV will be a product about being a decorative item. |
| date3 | | LP1 | The product display within the handicraft center will include a sample of the products above. And there are products for sale at the bottom of the exhibit. |

The researcher conducted a preliminary study on local wisdom from field visits. make participant observations to use the results of field visits to design interview tools. The tool was a semi structured interview. by asking several village sages 8 people by the nature of the questions divided into issues as follows: 1. Characteristics and strengths of local wisdom 2. Importance of occupation related to local wisdom 3. Transfer of knowledge about local wisdom 4. Materials and equipment used in making local wisdom 5. Processes used in making about local wisdom and 6. Guidelines for product development on local wisdom. The in-depth interview takes approximately 40 minutes per person.use audio recording The researcher asked for permission from a local philosopher to record the sound. Then, take the tapes of the interviews to make the tapes of the individual interviews. After that, make a return to the center for the village sage to check the accuracy of the interview.

The results of the study were analyzed using participant observation content analysis and interviews with local scholars. then analyze the content (content analysis) with the analysis steps. The researcher read all the information obtained then extract the data (segmenting) and can divide the collected data into all issues, 6 Issues as follows, 1. the identity of the umbrella 2. handicraft center 3. Guidelines for the transmission of wisdom 4. materials and equipment for making 5. how to make an umbrella and 6. Knowledge development of local wisdom. Then, gives the data code (coding) and considers all messages for encoding with details. Then the researcher made a codebook.

6. Knowledge development of local wisdom

**Table 2** Preview analyzes the content of the data collection.

| tool | Category | code | message |
|---|---|---|---|
| **Issues Handicraft Center** | | | |
| FN:1 | position | Lo1 | When entering the San Kamphaeng district, it is decorated with umbrellas. And there are shops selling umbrellas between both sides of the road. |
| FN:1 | | Lo2 | Area in front of the center There are photo spots, cafes, and gardens where you can sit and relax under the big trees. |
| FN:3 | | Lo3 | when tourists arrive when parking will walk into the inner area. Then walk straight into the area that makes the umbrella behind and go back to buy products inside |

The researcher made a transcript of interviews with several village scholars, and 8 people, then check with the informants (Member Check) and bring the interview results to the village sage to review the interview data that corresponds to the meaning given by the village sages. The researcher then conducted peer reviewers with peer review of the data and the results of the study to exchange with those who have expertise in the field of chemistry learning management and teaching and learning local wisdom, who is known and practiced teaching in Chiang Mai, to exchange and jointly analyze the results of the study whether it is consistent with the research process. Data collection and analysis to ensure accuracy, then the researcher brought the results of the study examining the triangles. (Triangulation) to check the consistency of the information that is correct, from various data collection methods whether a variety of sources various methods of data analysis, etc.

## 3. Findings

From the interviews with local scholars, it was found that the local wisdom of making umbrellas in BorSang is the local wisdom of the villagers of Ban Bor Sang. In the process of making umbrellas for Bor Sang, four steps, are 1) material preparation for the canopy 2) building an umbrella structure 3) sealing the canopy with the structure and 4) Painting and dyeing, each of which has a body of scientific knowledge as the following details,

**1). Material preparation for canopy**

In the body of knowledge, local wisdom, and umbrella-making, there is a selection of materials used to cover the umbrella with different properties as follows: 1. Type of paper (mulberry paper) and 2. The type of fabric (cotton) by the different properties of the two types of materials are different. By using the water-absorbing properties of the material as a criterion, it can be seen that the traditional umbrella cover that uses mulberry paper has more water-absorbing properties than the fabric group material. For the reason make the efficiency of use when water is absorbed, its performance decreases causing village sages to develop umbrella products to be able to use them with maximum efficiency as the interview follows:

I: Why are there so many products sold in the Umbrella Craft Center?

FP2: In the past, Bor Sang umbrellas were covered with mulberry paper, but there was a problem with the work, namely, they could only block sunlight. They can't prevent the amount of rain; therefore, customers rarely use the product. In the process of making mulberry paper from jute, there are a variety of methods and the high price is not suitable for use. At present, it is developed to cover umbrellas with silk, cotton, etc.

FP5: Paper [mulberry paper] will only block sunlight. But if it's a fabric [cotton], it will be coated with oil. So they can block sunlight and water. And it is more durable and uses fewer chemicals than paper [mulberry paper].


**Figure 1**: Bor Sang umbrella products that use different materials to cover the umbrella. (A) Cover the umbrella with mulberry paper (B) Cover the umbrella with cotton.

The change in chemical reactions of materials can be divided into2 forms: change in physical properties and chemical changes in the process of making paper. There is a process of making mulberry paper from pulp from the jute tree. The scientific name is Broussonetia Papyrifera. Chemical change has an observable point. The formation of new substances in the reaction showed that the chemical change in this process is the use of chemicals to perform chemical reactions to change the structure of the reactants. Figure 2 shows the process of making mulberry paper. Marked steps the (asterisk) chemically altered, found to have 2 steps: Step 2) soak the membranes in water and bring them to boil in sodium hydroxide (NaOH) solution for about 3 hours and wash until the solution is not alkaline; Washing and bleaching with hydrogen peroxide (H2O2). This two-step transformation is a chemical change that takes place and in other steps, it is the physical change of the reaction by simple classification. This may be done in the process of physical transformation when the product changes and the product can be converted back to a new substrate in the papermaking process.


Soak the hemp bark in water for approximately 3 hours


Bring to a boil in a solution of sodium hydroxide. (NaOH) about3 hours and rinse with water until the solution is not base


to be bleached with hydrogen peroxide


The jute fibers are mixed into the water to make the fibers float and separate.


Molds for making paper plates come fiber spoons.


to dry approx. 2 hours, then peel off the mulberry paper from the mold to get a sheet of paper out.

**Figure 2** shows the process of making mulberry paper from jute trees. to be used as a material to cover the umbrella.

The material used to cover the umbrella Materials based on natural polymers are selected according to the monomer structure, Homo-polymer. The material used to cover the umbrella is cotton and mulberry paper. Because it is a locally selected material that can be used locally. When analyzed, the two species were similar. It is composed of glucose monomer molecules connected by beta-glycosidic bonds (β Glycosidic linkage) known as the helix of the cellulose structure. In the process of preparing the material to cover the umbrella, there will be a process of dying to achieve beauty. The study found that in glucose molecules, there are groups that show negative ions. In the dyeing process, the solvent that is commonly used is water. In most processes, the water used has a weak pH value, causing the Hydroxy group on the cotton fabric to be ionized, causing more negative ions. The correction of the dyeing process that is commonly used by the villagers is the addition of metal mordant to create a complex with the complex color. Metal mordant that the villagers use most but do not adversely affect the environment is alum, and salt, the color used in dyeing is a kind of polyphenol. The dye can be absorbed in natural fibers. In addition, 80% natural color structure has a structure similar to acid dyes with a hydroxyl group. The -OH group helps the paint dissolve in water and exhibit a negative charge. When the paint dissolves in water, some colors consist of the pigment group as the main component of the color content. Therefore, each type of paint has a different dyeing process.

**2). Building an umbrella structure**

There is a selection of materials that have different components of the umbrella structure depending on the purpose of use. The first thing that should be known is the components of the umbrella are unique as shown in Figure 3 making the village sage choose different materials to make the structure of the umbrella for maximum efficiency in use as the interview follows:

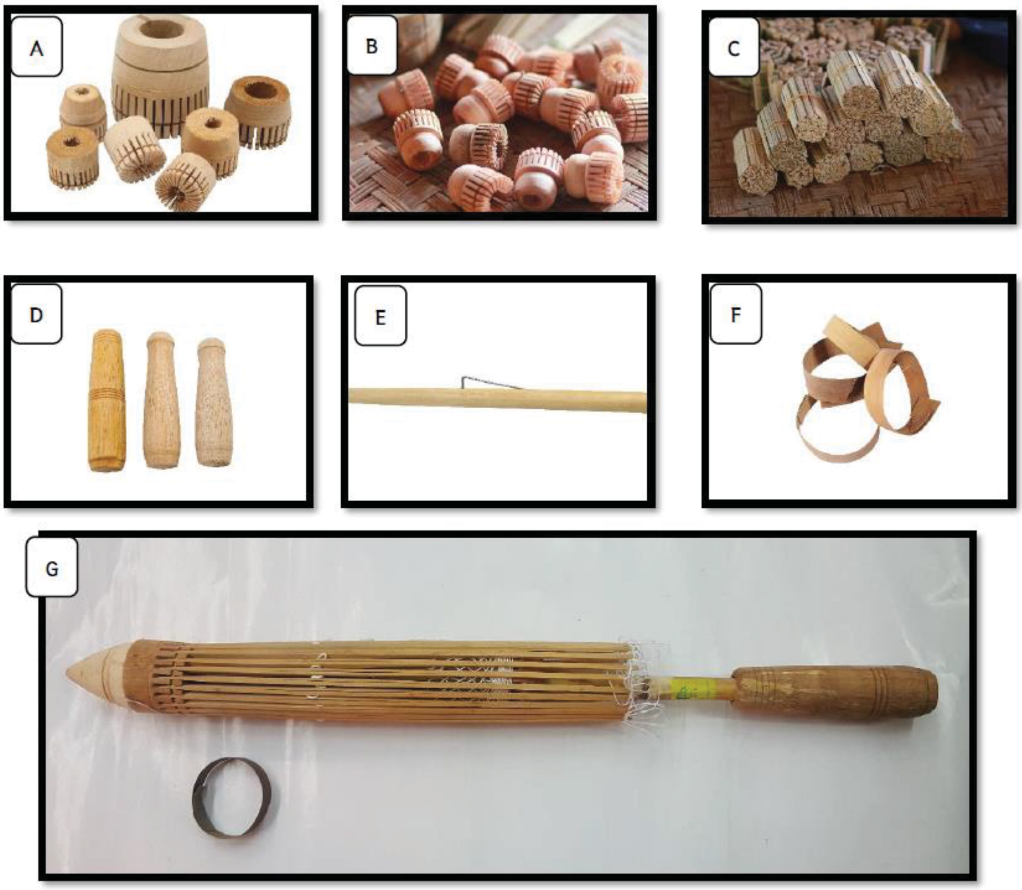


**Figure 3**: shows the components of the umbrella (A) umbrella head (B) bow (C) support (D) rod (E) horse (F) yard stripe (G) umbrella structure that puts all the parts together.

I: components that are used to make the frame of the umbrella, how do we use the same or different components?

FP6: The umbrella head is made of softwood such as trotters., Mushroom ridge, Kham Kham wood, and Kae wood. Components are used to secure the spokes by threading the thread to form an umbrella frame. The size of the head depends on the size of the umbrella and has different characteristics.

Bob is made of softwood as well as the inner part of the umbrella. Next down from the head is used to fix the ribs as a pusher for the umbrella horse to lock-in. Nylon threads are used to attach the bobbins to the struts.

The pole spokes are made of Gold bamboo because they are tough and durable. The bamboo spokes extend from the bottom of the ribs in terms of size and number, depending on the size of the umbrella. 10-14 inches will use 24 teeth, 17-20 inches will use 28 teeth, 40-60 inches will use 36 teeth, and the smallest will be 5 inches, will use 16 teeth in total. The number of spokes will be the same for both the support. For example, for a 20-inch umbrella, 28 spokes will be used for both the support.

The handle is made of small bamboo or softwood. It looks like the part that uses the handle of the umbrella. There are different sizes and styles of wood. There are sizes from size to size.10-12 inches and 14-20 inches. There are two types of wood used to make a rod. Or a hand holding a wooden stick to produce a rod for the same paper umbrella and the satin umbrella. Bamboo will be used to make rods for cotton umbrellas. The design of the wand depends on the craftsman who made it.

The horse (latch) for the small umbrella is made of steel springs. The large umbrella is made of bamboo hone. As usually attached to the long handle of the umbrella, the height or the low depends on the size of the umbrella.

The casing is made of palm leaves, acting as an up down movement. when unfolding or closing the umbrella it looks like a long, small brown leaf. Before using it, it is necessary to soak it in water for the toughness and durability of the palm leaves or casings. The size of the patio casing depends on the size of the umbrella.

I: What are the essential components of building an umbrella structure?

FP7: Making umbrella spokes. After getting bamboo, cut it into pieces. If it is bamboo with long segments, cut between the joints. But if it is a short piece of wood, cut it so that the joint is in the middle of the length of the log, which is cut equal to the size of the umbrella that will be made. For example, for an umbrella size 20 inches, cut bamboo 20 inches long, etc. When cutting bamboo into long pieces use a knife to scrape off the surface of the wood, then mark for drilling holes. Drill holes and string them together. Then it was assembled into an umbrella frame. as in Figure 4.


**Figure 4** Showing the process of making umbrella spokes (A) Steps to sharpening umbrella spokes (B) Complete umbrella spokes awaiting assembly.

**3). Sealing the canopy with the structure**

Take a piece of paper or cotton made on the umbrella frame by using the paste mixed with the rubber of the Tako fruit. The rubber from the Tako fruit is obtained by crushing the Tako fruit thoroughly. Then bring it to the marinade for approx.3 months, then used Tako latex will help fabric or paper. It can resist the growth of mold on the umbrella surface. When dried and then used to paint mixed with local rubber oil called Tang Eu oil. This umbrella is painted by applying a damp cloth over the desired umbrella. In the past, only 2 colors were applied to the umbrella. is red and black Red is derived from the color of red clay that is present in the mountains. The black part is obtained from fire soot mixed with rubber oil. In addition to cotton or paper umbrellas, silk, satin, or other materials can be used to cover the umbrella. as Figure 5.

**Figure 5** Shows the umbrella cladding process. (A) Apply Tako rubber to the umbrella frame. (B) White paper cladding on the umbrella frame.

The physical changes of the umbrella cladding process are evaporation of moisture on white paper. Then take the umbrella covered with white paper to dry in the sun. For the reason that to let the delight evaporate, then covered with another layer of mulberry paper. The transformation process that takes place at every step depends on placing the umbrella in the sun for evaporating the water mixed in the rubber from the Tako fruit, to make the rubber binder to the umbrella wrapper. The change of substance that occurs is physical because in the process of such change no new substances were formed.

**4). Painting and dying**

Painting and drawing patterns on umbrellas are the identity of the community at Bor Sang Umbrella Handicraft Center. By which the color of the umbrella will use the color of the pattern of the umbrella, it will be mostly natural patterns, which are designed according to the craftsmanship. Unless there is an order of products according to customer's size and color and customers can design patterns or messages according to their needs to be given as souvenirs on special occasions as well. By the nature of the basic patterns of the Bor Sang umbrella, identity is patterns related to nature, such as floral patterns, bird patterns, and butterfly patterns, which have evolved according to demand and time to change, with the development of artificial patterns up to many different patterns to meet the needs of consumers

coloring by color acrylic (Acrylic Color) to draw the pattern of the umbrella. Since acrylic paints are synthetic polymers in the form of functional group emulsion cross-linked esters of Acrylic and Methacrylic Acid, it is a viscous liquid. In general, applications are used with volatile solvents. Because when painting on the surface of the umbrella, the painted color needs to evaporate quickly. As in the interview as follows:

I: In the process of applying patterns and colors, what colors do you use?

FP7: The color used in the umbrella is acrylic paint. Because it dries easily and is long-lasting.

FP4: Popular motifs such as butterflies, birds, flowers, and elephants, and also developed into other products such as fans and mobile phone cases.


**Figure 6**: Shows the acrylic handicraft center products (A), umbrellas (B) phone cases, and (C) fans.

From the analysis of scientific knowledge of umbrella making which corresponds to the indicators of science learning subject in the core curriculum of basic education, B.E.2008 (Revised 2017) consistent with 1. Substance 2 Physical Science at the elementary school level until the upper secondary and 2. Additional science Chemistry at the upper secondary level with 4 steps as shown in Table 3.

**Table 3**: shows the process of making an umbrella for Bor Sang of San Kamphaeng District, Chiang Mai Province with the concept of science and related indicators according to the core curriculum of Thailand.

| Umbrella making process | Chemical science concept | Corresponding learning metrics | |
|---|---|---|---|
| | | physical science | Additional science, chemistry |
| **1. Material preparing for canopy** | material properties | V.2.1 P.1/1-2 | - |
| | chemical reaction | V.2.1 Grade 5/3-4, Grade 3/7-8 | - |
| | Polymer Chemistry | V.2.1 m.3/1-2 | chemical1 M. 6/11-15 |
| **2. Building an umbrella structure** | material properties | V.2.1 P.1/1-2 | |
| **3. Sealing the canopy with the structure** | chemical reaction | V.2.1 Grade 5/3-4, Grade 3/7-8 | |
| **4. Painting and dying** | Polymer Chemistry | V.2.1 m.3/1-2 | chemical1 M. 6/11-15 |

## 4. Conclusion

The study found that local learning resources that promote science learning management in local contexts can promote learning management at the primary and secondary levels of Thailand. The science teacher must study the body of knowledge from the local wisdom both in terms of materials and equipment. In the process of doing local wisdom studied science teachers then have to analyze the body of science related to the procedures or materials studied. Then when teachers can analyze the body of knowledge, Teachers will be able to analyze indicators and learning material from the basic education curriculum connected and consistent with the context of the community and enable learners to learn meaningfully and create a body of knowledge and can arouse the interest of learners in learning. Science teachers can provide guidelines for science learning management that rely on the integration of knowledge in the same course across learning subjects or can be integrated across groups of learning subjects.

Study limitations science learning resources of science teachers found that it is difficult to apply local wisdom to drive activities to promote science learning that can enable teachers to use continuity in teaching-learning activities. Because the process of local wisdom sometimes does not correspond to the teaching and learning process according to the indicators. As a result, in the development of science teaching and learning management guidelines, teachers should use the activities of the Department of Science Teaching to summarize the body of knowledge and be able to link scientific concepts with linking activities in daily life. And such teaching will cause learners to change their attitude toward science learning. Guidelines for learning management should be developed for science teachers to gain understanding and competence in good learning management.

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# A Study of Learning Management Model that Promotes Scientific Literacy for Pre-Service Teacher

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**Abstract.** This collaborative research aimed to synthesize a teaching model promoting scientific literacy and then monitor how pre-service teachers implement and experience it in real classrooms. Three science pre-service teachers who enrolled in the internship course participated in this study as case studies. Research data was collected by interviews and classroom observations and analyzed through content analysis. Method triangulation was used to ensure the credibility of qualitative data. The research findings indicated that the pre-service teachers had professional experience in the teaching model implementation in five aspects: 1) the limitations of the teaching model; 2) student scientific literacy; 3) self-awareness about teaching; 4) learning management; and 5) learning environment. Furthermore, the finding revealed that they, as science teachers, had to have enough scientific content knowledge to be able to critique and identify which content knowledge was relevant to a particular social situation. Then they used that situation to launch classroom discussion activities in the teaching model. If a science teacher were unable to identify a wide range of scientific knowledge, it would hinder their students' ability to link science in society.

**Keywords:** scientific literacy, learning management model that promotes scientific literacy, pre-service science teacher

## 1. Introduction

Science is one of the most important subjects of teaching and learning in the twenty-first century. It plays an essential role in raising public awareness in society because it enables people to develop rational and creative thinking, acquire the critical skills in knowledge research, systematically solve problems, make decisions based on a variety of data, and provide verifiable testimony. As above abilities are compatible with the International Student Assessment Program in Science Literacy (IPST, 2017), which evaluated 15-year-old pupils in all OECD nations, including Thailand.

The Program for International Student Assessment (PISA)PISA establishes a framework for the scientific assessment structure that consists of the first component context, scientific knowledge, and scientific competence by recognizing situations in life at the individual, national and global levels, even in the present or in the past. It is necessary to have understand of science and technology as well as an understanding of facts, key concepts, and crucial theories that form the basis of scientific knowledge. It contains knowledge of the natural world and technological inventions (content knowledge), knowledge of the methods of conceptualization (process knowledge), and an understanding of the fundamental rationale of the knowledge-building process. It contains knowledge of the natural world and technological inventions (content knowledge), knowledge of the methods of conceptualization (process knowledge), and an understanding of the fundamental rationale of the knowledge-building process (knowledge acquisitions ) in order to provide the ability to 1) explain phenomena in a scientific phenomenon, 2) assess and design processes in the pursuit of scientific knowledge, and 3) interpret data and use scientific testimony in which these three emphases are combined. People encounter with a range of real-life circumstances involving themselves, their communities, their countries, and the world. As a result, we must possess and employ the ability to respond to and solve situations in a fair manner. All of the above is called Scientific Literacy.

Scientific literacy is the ability of a person to communicate or argue about issues related to science and technology rationally. In which the person needs to know and use many elements, including the context or situation of science. scientific knowledge and scientific competence (PISA, 2018). Which at present There has been a rapid change in the economy and society, making human livelihoods. more relevant to science. However, the Program for International Student Assessment (PISA) measures competence in all three areas: reading, math and science. In terms of science, Thai students tended to have better results in science assessments than reading and math. Approximately 56% of Thai students have a science proficiency at level 2 or higher. The average of OECD member countries is 78% of students with this level. By this level, students can obtain accurate descriptions of familiar and not too complex scientific phenomena. Scientific knowledge can be used to tell whether the conclusions are accurate and consistent with the available data.

All The Institute for the Promotion of Teaching Science and Technology (IPST, 2018) states that in the latest 2018 Science Intelligence Assessment, Thai students had an average reading point of 393 (OECD with a mean of 487) 419 Mathematics points (OECD with a mean of 489) and 426 Science points (OECD with a mean of 489) when comparing to PISA 2015, there was a 16 point decrease in reading for reading. Mathematics and Science were increased by 3 points and 4 points respectively. For the statistical test, the math and science aspects were unchanged compared to the previous assessment cycle. However, when analyzing the trend of point changes from the first round of assessments to the present, it found that mathematics and science assessment results in Thailand were unchanged. The reading assessment results tended to decline continuously.

Based on the above situation, Muhammet (2020) suggested that developing learners to become scientifically literate students may need to be cultivated at an early age and related departments. It should make scientific literacy the goal of science education at the elementary level. This is because learning at the elementary level is the first step of compulsory education (Compulsory Education) that builds on learning at the early childhood level, and is a crucial time in life for identity development. It is an educational level that aims to lay the foundations of life in every aspect, including reading, writing, numeracy, and fundamental subjects. The development of knowledge and skills acquired during this period will be the fundamental cost for further development of knowledge and skills in secondary education (Jaiyeoba, 2011). But if the learners who start their education poorly are typically unable to make good progress in the following years (Burcu ÖKME, Şeyma ŞAHİN, Abdurrahman KILIÇ, 2020). Therefore, building a foundation of scientific literacy for learners under the age of 15 will help students succeed in their future life.

This is due to the fact that students must live in a fast-changing environment based on reason and consequence, as well as apply their scientific knowledge to make educated judgments in the context of the sciences around them. Reasons for this (Muhammet, 2020) Learners will be able to learn and advance if they can adjust to the changes that occur. On the other hand, if students are unable to adjust to changes in the interface, this failure to adapt might represent a significant barrier to learning. As a result, it is the teacher's responsibility to encourage and assist students in learning science in a meaningful way. On the other hand, teachers are critical to students' learning, particularly throughout the student experience, since it prepares them for future real-world practice. Students can face real-life issues involving self, local, country, or global situations and reasonably solve problems if pre-service teachers exercise professional experience.

All above- mentioned studies, the researcher is interested in studying the effect of using a learning management model that promotes scientific literacy. Pre-service teachers practice teaching professional experience that the researcher has synthesized from various research studies to be the benefits in learning management, promoting scientific intelligence for pre-service teachers to practice teaching a professional experience to be more effective.

## 2. Methodology

This paper is a qualitative research case study with interpretation and content analysis methods as follows:

### *2.1. Target group*

The participants consisted of three general science pre-service teachers studying in the second semester of Academic Year 2021. They were selected by purposive sampling as university students who are training about teaching in the school and who are responsible for the management of science learning in grade 7-9, 2nd semester, and the academic year 2021 at 3 large schools in Phetchabun as shown in Table 1.

**Table1:** showing the fundamental information of the participant

| Schools | Code | Level class responsibility | Content | Hours |
|---|---|---|---|---|
| A | ST1 | Grade 7 | Weather forecasting | 3 |
| B | ST2 | Grade 8 | Earth's Changing Surface | 3 |
| C | ST3 | Grade 9 | Components of Ecosystem | 3 |

### *2.2 Methods of Inquiry*

For this research, the data collection was conducted by interviewing pre-service teachers with professional experience before and after each teaching, face-to-face during the interview. The researcher requested permission to record the conversation for use in transcription. The conversation was sent back to the interviewed pre-service teachers to check for a member check. In addition, the researcher made a note of noticeable points during the interview and while the students were teaching. The researcher also observed the teaching of the students at all times.

Qualitative data analysis, was used by bringing the chapter interview for preparing and the information for coding and categorizing that correlated according to the issues coded and brought to conclusions using evidence from interviews and report the results of a detailed analysis of interviews with examples of thick description.

The reliability of the data analysis results was checked during the conduct of the research. The researcher will discuss the data collection and analysis results with peer debriefing and check by member checking.

## 3. Research Findings

Research findings on the study of the use of a learning management model that promotes scientific literacy. The researcher will report on two objectives: synthesis of learning management model that promotes scientific intelligence; For pre-service teacher and to study the effect of using a learning management model that promotes scientific literacy for pre-service teacher in order of research objectives

*Research objective 1* : To synthesize a learning management model that promotes scientific literacy for pre-service teachers

**Table 2** : shows a synthesis of learning management models that promote scientific intelligence.

| **Model 1 (Sri Rahayu.2017)** | **Model 2 (Ashlyn E. et. al. 2020)** | **Model 3 (Kultida. et. al. 2018)** | **Model 4 (Eliyawati et. al. 2017)** | ***New Model*** |
|---|---|---|---|---|
| 1) Choose a chemistry content that has characteristics of rich applications in daily live | 1) Review article | 1) Motivation | 1) Contact Phase | **1) Choose situation in daily live** |
| 2) Utilize inquiry and constructivist approach | 2) Test | 2) Exploration | 2) Curiosity Phase | **2) Brainstorming** |
| 3) Integrate nature of science (NOS) | 3) Group to work | 3) Brainstorming | 3) Elaboration Phase | **3) Exploration** |
| 4) Construct socioscientific issues related chemistry | 4) Presentation and discussion | 4) Decision making | 4) Decision Making Phase | **4) Decision making** |
| 5) Allow students to collaborate each other to solve a problem | - | - | 5) Nexus Phase | **5) Application** |
| 6) Allow students to communicate | - | - | 6) Assessment Phase | - |
| 7) Choose interesting | - | - | - | - |

| Model 1 (Sri Rahayu.2017) | Model 2 (Ashlyn E. et. al. 2020) | Model 3 (Kultida. et. al. 2018) | Model 4 (Eliyawati et. al. 2017) | *New Model* |
|---|---|---|---|---|
| socioscientific / contemporary issues to increase student's curiosity. | | | | |

Learning management that promotes scientific literacy that the researcher has synthesized from there are details in each step of learning management such as teaching principles in each step, goals, roles of teachers, and roles of learners. Which will be reported as shown in table 3.

**Table 3** : Details in each step of learning management step.

| New Model | Teaching principles | Goals | Roles of teachers | Roles of learners |
|---|---|---|---|---|
| 1) Choose situation in daily live | Teachers provide situations that occur in everyday life. and related to science as an import to the learning of the class and using questioning to get students to identify science-related issues. | identify science-related issues. | - Provide situations that occur in everyday life<br>- Open-ended questions<br>- Give more feedback | - identify science-problem<br>- answer |
| 2) Brainstorming | Brainstorming within groups to analyze, understand, and identify knowledge relevant to the situation. Problems or knowledge that require further from the situation to use for proof or problem solving | - Identify of scientific knowledge relevant to the situation | - Use questions to make students relate their science knowledge to the situation. | - Exchanging knowledge within the group<br>- Analyze and understand the problem<br>- Communicate knowledge that comes out |
| 3) Exploration | Exploring and searching for knowledge, such as searching, experimenting, asking people who know, or observing related phenomena. | - Scientific inquiry | - Use causal questions in order for students to have a process of thinking from the result of the inquiry | - Search for information (evidence) that you want to know more<br>- Use science process skill for scientific inquiry |

| New Model | Teaching principles | Goals | Roles of teachers | Roles of learners |
|---|---|---|---|---|
| 4) Decision making | Must decide on a solution to the problem. of the group thought to be the best overall method | - Explaining the situation with scientific evidence | - Use open-ended questions to point out different opinions. to give students more options and allow learners to express their opinions in a variety of aspects | - Use testimony Scientific evidence for opinion or argued on some issues |
| 5) Application | To use the body of knowledge on that subject to explain and make decisions in different situations | - Explaining the situation with scientific evidence | - Use open-ended questions<br>- provide different situations<br>- Encourage students to use the knowledge they have acquired to critique new situations. | - Explaining the situation with scientific evidence<br>- Make decisions in different situations |

The researcher conveyed the teaching method by mutual understanding with the students through a step-by-step guide. to create understanding As an example of this conversation

*"I am so confused. Brainstorming and Exploration, I think it's confusing. Because after brainstorming and researching for answers, it would cause the teaching to overlap."*

*ST1, 15 February 2022*

Researchers and pre-service science teachers work together to come up with situations that can be used in learning activities. An example of the instructor's answer in selecting the situation "5000 liters of oil leak in Rayong", which the instructor commented on.

*"This situation should be suitable for students. because it is an issue that is not an issue for long Students may have heard of it. and close to you as well."*

*ST3,17 February 2022*

When some steps get confused The researcher explained further. along with an example to illustrate for students to visualize and more understand. This synthesized form of learning management to promote science literacy was applied to learners at all three levels. Therefore, the researcher will continue to report the results of using the learning management new model as the second objective.

*Research objective 2* : To study the effect of using a learning management model that promotes scientific literacy for pre-service teachers

From the interview first question found that after the management of science learning. The students were interviewed as follows:

*Researcher: What do pre-service teachers think they have learned from using a learning management model that promotes scientific literacy?*

*ST1 : After teaching I think that the management of science learning that makes the learners to be intelligent and knowledgeable of science. It is necessary to link knowledge from situations that are well applied at the beginning of the hour.*

*ST2 : I think the teacher's scientific knowledge must be very accurate because it must be used to explain phenomena with rationality.*

From the interview was concluded that the pre-service teachers are the importance of scientific knowledge and the situation used including explaining the phenomena that occur rationally.

When experimenting with teaching to promote scientific literacy can report the results of the experiment in five aspects as follows:

1) The limitations of the teaching model;

This New model is specific to content that can be applied to real-life situations such as force and motion. It is therefore important to organize learning in order. As a research by Kultida Chanapimuk. et. al. (2018), which included the subject matter that raised the question of students with environmental problems. And the next step will make students ask various questions. And the questions can be separated into issues so that students can see the categories of questions. and guidelines for finding answers. An additional finding from using the learning management model to promote scientific intelligence is that students are more assertive. As opposed to the information that the teacher gave before planning to learn that the students in this room would not dare to express themselves. or comment in class. In addition, another important finding was that the teacher's questioning skills had to be very good. because the teacher was unable to control the situation or directions for sharing information that learners find from the social media. Questioning skills to come to a common conclusion therefore important and it's part of the classroom management this time as well. It can be seen from the interview as follows:

*Researcher : What problems in this teaching ?*

*ST3 : The teacher's questioning is not diverse enough. because I will only ask the content No connection to the situation Therefore, students are unable to explain the phenomenon in a scientific way.*

2) Student scientific literacy;

Student still can't identify the issue and scientific knowledge relevant to any given situation. And learners can create descriptions. But still unable to find evidence to support the scientific explanation (Benjamin C. Herman et al., 2019). As an example of student work as shown in Figure 1.

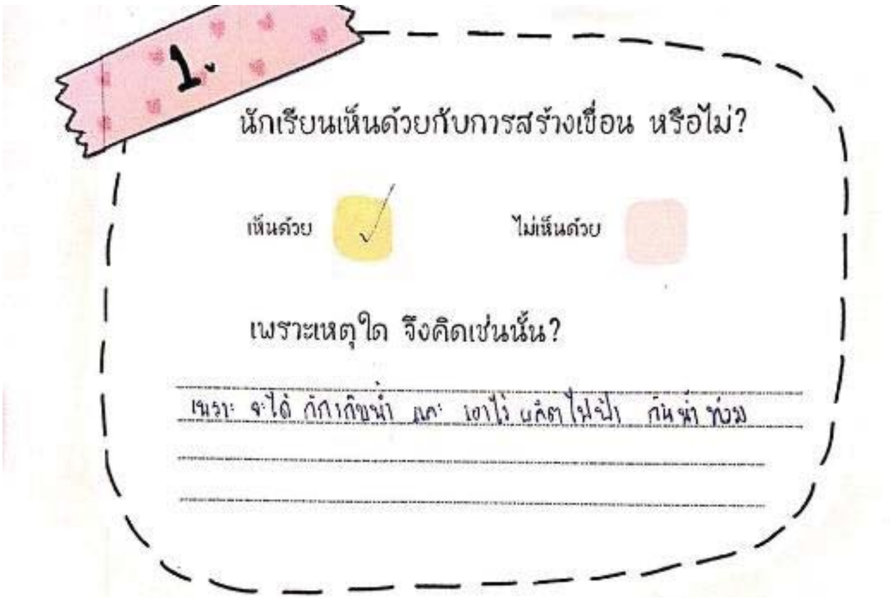


Figure 1 : Example of student work 1

From Figure 1, students can see that agree or disagree with the situation adopted for 'building a dam', but it's still not very good to explain the evidence to support your opinion reason to come also a common reason not as specific to the situation as it should be and not enough information. The opportunity for students to find information is another interesting point. Because finding information to support their own opinions obtained from unreliable sources as shown in Figure 2.

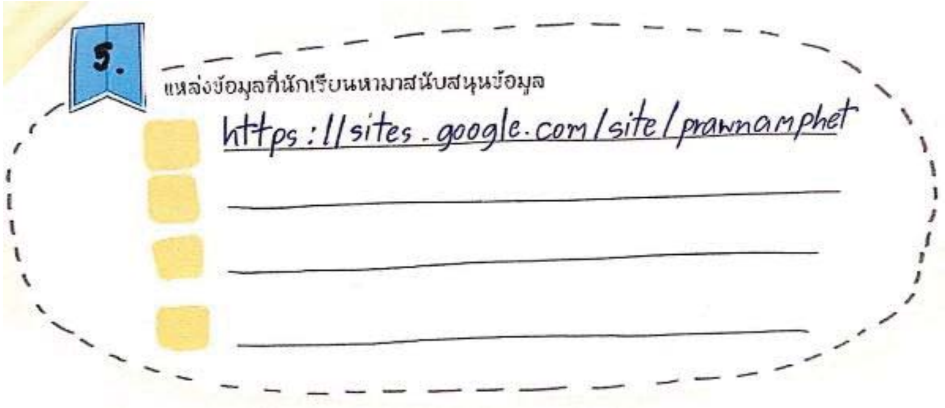


Figure 2 : Example of student work 2

The information that students gathered to support their opinions was obtained from general websites. That is not specific to scientific knowledge. As a result, students are unable to explain their opinions reasonably.

3) Self-awareness about teaching;

Teachers must therefore use questions to come to a conclusion or reasonable explanations with evidence to enable learners to understand scientific content. Teachers must have the skills to connect science content to their surroundings for teachers. If the teacher has no knowledge of the content, the teacher will not be able to relate the content to any situation at all. (Koh & Chai, 2014)

4) Learning management;

The duration of the activities should be sufficient for gathering information and evidence to create an explanation. The nature of the situation must be real daily life or hot issue.

5) Learning environment.

Environment for learning management students must learn in groups. Because of the step brainstorming is required to identify the knowledge relevant to the situation. And the teacher's classroom management must be relaxed. Do not put too much pressure on students.

Furthermore, the finding revealed that they, as science teachers, had to have enough scientific content knowledge to be able to critique and identify which content knowledge was relevant to a particular social situation. Then they used that situation to launch classroom discussion activities in the teaching model. If a science teacher were unable to identify a wide range of scientific knowledge, it would hinder their students' ability to link science in society.

## 4. Conclusion

The conclusion indicated that the pre-service teachers had professional experience in the teaching model implementation in five aspects: 1) the limitations of the teaching model; 2) student scientific literacy; 3) self-awareness about teaching; 4) learning management; and 5) learning environment. Furthermore, the finding revealed that they, as science teachers, had to have enough scientific content knowledge to be able to critique and identify which content knowledge was relevant to a particular social situation. Then they used that situation to launch classroom discussion activities in the teaching model. If a science teacher were unable to identify a wide range of scientific knowledge, it would hinder their students' ability to link science in society.

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# A Physics Teachers' Technological Pedagogical Content Knowledge and Problems in the Instructional Management under the Secondary Educational Service Area Office Sukhothai in the Situation of Coronavirus Pandemic

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**Abstract.** The COVID-19 pandemic has changed education to integrate more technology in classroom. Technological Pedagogical Content Knowledge (TPACK) is an essential framework that teachers need to know in order to teach with technology effectively. This study examined the TPACK and problems in the instructional management during the COVID-19 pandemic held by 16 physics in-service teachers who teach at schools under the secondary educational service area office Sukhothai. Data sources consisted of questionnaires from 16 teachers and semi-structured interview with 5 teachers. Content analysis was used in data analysis and peer debriefing was used for ensure the trustworthiness in this study. This result revealed that these in-service physics teachers do not have appropriate technological pedagogical content knowledge. They have content knowledge, pedagogical knowledge, pedagogical content knowledge and technological knowledge at good level but, they have technological content knowledge, technological pedagogical knowledge and technological pedagogical content knowledge at low level. In addition, while the COVID-19 pandemic, most schools offered online teaching. Most physics teachers have incomplete level of technological pedagogical content knowledge. The problems that the teachers identified that they encountered in their teaching are 1) In terms of learning management, teachers are unable to manage teaching and learning that emphasizes students' inquiry because the students could not do the experiment or do activities that focus on inquiry, thus the teaching focus solely on Lecture 2) Teachers are unable to integrate the technology in their teaching. and 3) Students are not ready for online teaching, due to lack of learning equipments including computers, telephones and internet.

**Keywords:** Technological Pedagogical Content Knowledge, Problems in the Physics Instructional Management, COVID-19 Pandemic

## 1. Introduction

Back to 2019, the coronavirus pandemic changed the education system around the world. Teaching and learning were completely changed. Thailand is one of the country that has most affected. That effect to schools across the country are unable to organize teaching and learning as usual. During the coronavirus pandemic, most of school are using online teaching. when the covid-19 situation has softened, cause people including students and educators are vaccinated. The Ministry of Education has considered allowing schools can open normally (Onsite). If students or educators had infected, the school will consider an appropriate teaching and learning style, that creating a hybrid learning approach. Hybrid learning approach is the appropriately face-to-face and online learning, emphasizing a variety of teaching methods to enable learning interactions between teachers and students through tools, software, and information technology to integrate with teaching and learning to increase efficiency in learning management.

Research findings have shown that technology has a great influence in changing the way of teaching and learning science. Especially in physics subject that are important in science learning because physics is a fundamental content that leads to understand of other fields of science. It is a theme that can be linking the daily events, thereby promoting the understanding of more complex concepts. (Matthews, 1997; Sadler and Tai, 2001; Pruekpramool and Sangpradit, 2016). Moreover, the physics content is quite abstract because the nature of the subject talks about all natural phenomena. Including the knowledge of physics is also obtained from the imagination by creating an idea model using the principles of physics which leads to a theory conclusion and experiments to verify that theory. Therefore, learning physics is difficult to make students understand the concept. Then, integration of technology is essential for physics teaching and learning management. Several relevant research studies indicate the effective of technology in enhancing learning. It helps students come up with ideas. It helps to understand abstract things. It helps to engage and create a positive attitude towards the subject. It is increasing interaction between teachers and students and between students and students. (Cunningham & Carlsen, 2014; Goldfarb, Pregibon, Shrem, & Zyko, 2011; Savasci & Berlin, 2012; Wenglinsky, 2005)

Technology plays a role in teaching physics. However, there is still need to study how to integrate technology into teaching and learning management that can support science teaching. (Osborne and Hennessy, 2003) it can be said that physics teachers lack of technological pedagogical content knowledge (TPACK), which is an important factor in effective learning management. TPACK is a theory which presents the relationships between the technological, pedagogical, and content knowledge of teachers and students. Mishra & Kohler (2006) define TPACK theory as the interaction and communication among these three types of knowledge. There are three interconnected components: technological, pedagogical, and content knowledge. Explanations regarding these are given respectively, as follows. Technological knowledge (TK), Pedagogical knowledge (PK), Content knowledge (CK), Pedagogical content knowledge (PCK), Technological content knowledge (TCK), Technological pedagogical knowledge (TPK), and Technological pedagogical content knowledge (TPACK). This is a challenge for teachers. Therefore, the understanding of problems in physics teaching and learning and the teachers' technological pedagogical content knowledge (TPACK) will be the basic information for use as a guideline for physics teacher professional development.

## 2. Methodology

This research is survey research that presents both quantitative and qualitative data. Using content analysis and descriptive statistics to analyze the data. This research aimed to 1) Investigate physics teachers' Technology Pedagogy and Content Knowledge.

(TPACK) 2) Investigate the Problems in the Physics Instructional Management in the Situation of Coronavirus Pandemic.

*2.1. The participants*

The participants were 16 in-service teachers who under the secondary educational service area office Sukhothai.

*2.2 The research instruments*

The research instruments in this study include

1. Questionnaires on learning management problems and level of TPACK of physics teachers. The questionnaires are an open-ended question divided into 3 parts as follows:

Part1 Question about teachers' basic information such as gender, age, teaching experience.

Part2 Question about the level of teachers' TPACK.

Part3 Question about problems with teaching and learning management.

2. Semi-structured interview. It was an interview for in-depth information after a physics teachers answered a questionnaire.

Researcher brought all of research instruments to the experts for checking the suitability then used to collect the data.

*2.3 Data analysis*

Researcher analyzed the data from the questionnaires and interviews by using content analysis. To analyze the data from the questionnaire, researcher compiled the data and grouped the data obtained to create conclusions on various issues. The level of teachers' TPACK questionnaires applied from Schmidt et al. (2009) and Tzu-Chiang Lin et al. (2012) and using likert Scale for analysis the data. The analysis of the data from the interview, researcher start with a transcript of the interview tape then organize information to group the data and make a conclusion and see the consistency with the data obtained from the questionnaire. Peer debriefing was used for ensure the trustworthiness in this study.

## 3. Research Findings

*3.1. Preliminary information of the respondents.*

16 physics teachers from schools under the Sukhothai Secondary Educational Service Area Office. There were 5 males and 11 females. Classified by educational qualifications, they can be divided into 2 groups: 7 teachers graduated from a faculty of science degree and 9 teachers graduated from a faculty education degree. Classified by age, it was found that there are 3 teachers in range of 22-25 years, there are 4 teachers in range of 26-35 years, there are 8 teachers in range of 36-45 years, there is 1 teacher in range of 45-60 year. Classified by teaching experience can be classified as 1-2 years physics teaching experience had 3 people, 3-10 years had 6 people, 11-20 years had 6 people and more than 20 years, there is 1 person. and classified by grade level, there are 6 teachers is in grade 10, there are 5 teachers is in grade 11 and there are 4 teachers is in grade 12.

*3.2. Technological Pedagogical Content Knowledge*

Teachers' technological pedagogical content knowledge in each component follows Mishra and Koehler (2006) framework. There are 7 components of TPACK, Content Knowledge (CK), Pedagogical Knowledge (PK), Pedagogical Content Knowledge (PCK), Technological Knowledge (TK), Technological Pedagogical Knowledge (TPK), Technological Content Knowledge (TCK), and Technological pedagogical content knowledge (TPACK or TPCK) by showing the frequency and percentage in each component. The details are follows table 1

Table 1: The frequency and percentage of teachers' TPACK

| Level | Mean score and percentage of teachers' TPACK | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | CK | | PK | | PCK | | TK | | TPK | | TCK | | TPACK | |
| | f | % | f | % | f | % | f | % | f | % | f | % | f | % |
| Lowest | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Low | 1 | 6.25 | 1 | 6.25 | 0 | 0 | 2 | 12.50 | 1 | 6.25 | 3 | 18.75 | 7 | 43.75 |
| Medium | 10 | 62.50 | 9 | 56.25 | 9 | 56.25 | 7 | 43.75 | 9 | 56.25 | 8 | 50 | 5 | 31.25 |
| High | 5 | 31.25 | 6 | 37.50 | 6 | 37.50 | 5 | 31.25 | 5 | 31.25 | 5 | 31.25 | 3 | 18.75 |
| Highest | 0 | 0 | 0 | 0 | 1 | 6.25 | 2 | 12.50 | 1 | 6.25 | 0 | 0 | 1 | 6.25 |

Content Knowledge (CK)

It was found that there are 10 teachers (62.50%) had moderate level of content knowledge, 5 teachers (31.25%) had a high level of content knowledge, and 1 teacher (6.25%) had low level of content knowledge.

Pedagogical Knowledge (PK)

It was found that there are 9 teachers (56.25%) had moderate level of pedagogical knowledge, 6 teachers (37.50%) had a high level of pedagogical knowledge, and 1 teacher (6.25%) had low level of pedagogical knowledge.

Pedagogical Content Knowledge (PCK)

It was found that there are 9 teachers (56.25%) had moderate level of pedagogical content knowledge, 6 teachers (37.50%) had a high level of pedagogical content knowledge, and 1 teacher (6.25%) had highest level of pedagogical content knowledge.

Technological Knowledge (TK)

It was found that there are 7 teachers (43.75%) had moderate level of technological knowledge, 5 teachers (31.25%) had a high level of technological knowledge, 2 teacher (12.50%) had highest level of technological knowledge and 2 teacher (12.50%) had low level of technological knowledge.

Technological Pedagogical Knowledge (TPK)

It was found that there are 9 teachers (56.25%) had moderate level of technological pedagogical knowledge, 5 teachers (31.25%) had a high level of technological pedagogical knowledge, 1 teacher (6.25%) had highest level of technological pedagogical knowledge and 1 teacher (6.25%) had low level of technological pedagogical knowledge.

Technological Content Knowledge (TCK)

It was found that there are 8 teachers (50.00%) had moderate level of technological content knowledge, 5 teachers (31.25%) had a high level of technological content knowledge, and 3 teacher (18.75%) had low level of technological content knowledge.

Technological pedagogical content knowledge (TPACK)

It was found that there are 7 teacher (43.75%) had low level of technological pedagogical content knowledge, 5 teachers (31.25%) had moderate level of technological pedagogical content knowledge, 3 teachers (18.75%) had a high level of technological pedagogical content knowledge, 1 teacher (6.25%) had highest level of technological pedagogical content knowledge.

*3.3. The Physics Instructional Management.*

Researcher presents the scenarios of physics teaching and learning in the situation of the corona virus pandemic. The problems were divided into 3 aspects: 1) The aviability of the equipment. 2) The presence of students and teachers. and 3) Physics learning management. The details are follows:

1. The availability of the equipment.

It was found that there were 2 problems, the first issue related to the equipment that used in learning. Students do not have learning equipment to use for online learning, such as mobile phones, computers, notebooks, and iPad. Causing students unable to study normally. As shown in the example of the teacher's answer as follows:

"Students are poor. They do not have equipment for study."

(Teacher, answering the questionnaire, January 2022)

"Students have unavailable online learning materials."

(Teacher, answering the questionnaire, January 2022)

"Sometimes we understand students. They don't have the learning equipment to use for online learning. Maybe I have to teach them later."

(Teacher, telephone interview, January 2022)

The second issue was the internet system. It was found that the internet was unstable in some areas, causing the teaching to be unstable. As shown in the example of the teacher's answer as follows:

"The internet for both teachers and students are unstable."

(Teacher, answering the questionnaire, January 2022)

"The online device is not ready. There is no internet."

(Teacher, answering the questionnaire, January 2022)

"Teachers and students' devices are not ready to use for online learning. There are no devices that support online learning. There is no internet package to support the study."

(Teacher, answering the questionnaire, January 2022)

2. The presence of students and teachers.

Regarding the presence of students, it was found that the students did not concentrate on online learning, lack of responsibility for attending online classroom, the environment is not conducive to studying. As an example of the teacher's answer as follows:

"The availability of students is insufficient. When they study at home, the environment is not suitable for learning."

(Teacher, answering the questionnaire, January 2022)

"The interest and discipline in attending online classroom has decreased. Cause they lack of responsibility in learning."

(Teacher, answering the questionnaire, January 2022)

Regarding the presence of teachers, it was found that because it was a new teaching style, they don't habitual for online teaching and most of teachers cannot use technology in their teaching. As an example of the teacher's answer as follows:

"Teachers do not have technology skill. Therefore, it is difficult to use technology for teaching and learning. At least, just open the video for students to watch or let students use it to search."

(Teacher, telephone interview, January 2022)

"I have tried not to lecture, but it's inevitable. I also try to use more technology for online teaching but, it will take time to adjust and study the further."

(Teacher, telephone interview, January 2022)

3. Physics learning management.

Schools use an online learning model through the Google Classroom platform, with most schools providing lecture-based instruction. For example, physics problems solving and let students practice problems solving by themselves. Some schools were demonstrating the experiments and ask questions to learn physics concepts. Some of schools are using technology to help manage physics learning, for example asking students to search the information from search engine, demonstration of experiments through various physics applications, etc. As an example of the teacher's answer as follows:

"Most of them will focus on lecture style and let students practice problems solving."

(Teacher, answering the questionnaire, January 2022)

"We tried to do experiment for showing students through the camera. Maybe open an experimental video or physics applications and discuss the results of the experiment together."

(Teacher, telephone interview, January 2022)

The problems encountered in teaching physics in the situation of the corona virus pandemic because the teaching and learning is an online. The problem is teachers are unable to organize activities for students to perform experiments. The student's participation in learning is reduced, such as expressing opinions, working together, asking questions, etc. As an example of the teacher's answer as follows:

"Teachers are not familiar with the method. It is difficult to communicate for students to understand. Some topic of physics content can do the experiment to show the concept, but they can't."

(Teacher, telephone interview, January 2022)

"Physics is a subject that needs to be explained and there are some experiments to help students understand better. There are also calculations that start from simple to complex calculations. Sometimes students do not catch up the idea and do not dare to ask during study."

(Teacher, answering the questionnaire, January 2022)

In addition, another problem is the assessment during the online teaching. The results showed that Teachers have difficult to create the assessment scales. Using an online exam could not truly measure students' knowledge because students can ask each other about the questions. Therefore, that make the result from the assessment results are inefficient and unreliable. As an example of the teacher's answer as follows:

"Evaluation is difficult because it is an online exam Students can copy the answers."

(Teacher, telephone interview, January 2022)

"There is no control over taking online exams. Students can find answers on the Internet.

(Teacher, telephone interview, January 2022)

From the research results, it can be seen that most of schools' teaching and learning style during the covid-19 pandemic is online. Therefore, the teaching and learning management of physics has completely changed. However, the level of teachers' TPACK depend on various factors. I will present of the level of Physics teachers' TPACK. The researcher presented in 2 issues with details as follows:

1. The level of physics teachers' technological Pedagogical Content Knowledge.

Start with content knowledge, most of physics teachers had moderate to high level of content knowledge. there are 5 teachers who have a high level of content knowledge. This is because they had graduated in faculty of science. They can understand physics concept perfectly. On the other hand, teachers who do not have a graduated in faculty of science but graduated in faculty of education found that knowledge of physics content was at a moderate level. But the knowledge of pedagogy knowledge will be at a high level. Teachers can organize teaching activities that are consistent with the content, able to bring students into the learning process appropriately, and able to follow the students' learning as well. But I'm not sure if we asking about who is better between the teacher who graduated in faculty of science or education. I think it's depended on teaching strategies and some learning management technic. that why most physics teachers had moderate to high level of Pedagogy Content Knowledge.

Technology knowledge, found that most physics teachers had moderate to high level of technology knowledge. Teachers have basic knowledge to use technology such as computers, internet, video media, etc. They also can learn how to use technologies. In addition, it was found that there are 2 teachers with a highest level of technology knowledge, it was found that these 2 teachers are assistant teachers. (22–25 years old) they can learn and access the modern technology is easier than older teacher. This is consisting with the research findings that there are 2 teachers with low level of technological knowledge, of which these 2 teachers are in the age range of 36-45 years. This is show that the age of teachers affects the learning of technologies, which will affect to the technology knowledge of each person. Also, consistent with Alison Gopnik (2019) that study of problem-solving learning among teenagers and adults. found that teenagers can learn better than adults. This is because teenagers have many different learning methods and strategies for learning. On the other hand, adults who tend to use traditional learning, if they find it difficult to learn and the methods, they use cannot learn it. They wouldn't want to learn. It also inconsistent with Alison Gopnik (2019) because there is 1 teacher who 45 year old have high level of technology knowledge. The data from teacher' interview found that. teachers are constantly improving themselves by learning to use new technologies through training or asking from teenagers in the school. That mean age doesn't have much effect on learning technology.

Technology pedagogy and content knowledge related to technology pedagogy knowledge and technology content knowledge. The research results, it was found that most teachers had moderate level of knowledge in these two areas. They can facilitate students to use technology to find out more about their learning. They can facilitate students to use technology in planning and follow up on their own learning. They can facilitate students to use technology to create various forms of knowledge representation, etc. In addition, they can use software created especially for science. They have technology knowledge that required for teaching and learning science content. However, when teachers have to combine technology, teaching methods and physics content together. It is going to be difficult for them. This is consisting with research findings that show that most physics teachers had low level of technology pedagogy and content knowledge. This is because teachers are accustomed to teaching in normal situation. In other words, teachers often use lecturing and experimental that relies on the tools and experimental equipment in schools. But when teaching and learning management have changed to an online, teachers have to change the way of teaching and learning. causing the teacher become unfamiliar and don't know how to start. It consists with Guzey, S. S., & Roehrig, G. H. (2009) they study of teaching science through technology. It was found that teachers were unable to integrate technology into learning management because they lack of familiarity using technologies that specific with content. Unable to decide how and when to use technology to manage learning. Teachers have no background in using technology and do not know how to solve the problems when technology do not work.  Therefore, they do not dare to use technology in their teaching.

In addition, the researchers had interviewed teachers for more information about using technology in their teaching. The result show that although teachers have used technology but, the use of technology is not used in the form of integration into teaching and learning physics. It is only used as an online classroom platform. The teaching process still focuses on lectures as before.

## 4. Conclusion

While the corona virus pandemic schools under the Sukhothai Secondary Education Service Area Office. All of schools offer online teaching and learning. But, also use another learning style such as on-demand, on-air, on-hand. There are 3 parts of problem in physics teaching and learning in the situation of the corona virus pandemic. 1) The availability of the equipment. 2) The presence of students and teachers. 3) Physics learning management. However, online teaching management during covid-19 situation will success is depended on the presence of many factors as a driver, including the availability of teachers and students, context of content, learning materials, learning management process, communication system, information technology network system, and learning achievement evaluation. (Wittaya Wayo et al., 2020)

## 5. Acknowledgements

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

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**Abstract.** This study aimed 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 on this topic, such as misconceptions, misunderstandings, or no improvement of understanding (Rahayu, Treagust, & Chandrasegaran, 2021; Tien & Osman, 2017; 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 and a challenge for teaching and learning (Kempler, Boettcher, & Ardo, 2021; Supasorn, 2015; Ahtee, Asunta & Palm, 2002; Garnett & Treagust, 1992a; 1992b; Johnstone, 1991; Linford, 1961). These pedagogical difficulties should be solved. One important learning behavior that can indicate the achievement of students' learning is constructing an explanation of the scientific content they learned. Explaining ability has been stated as the central aim of learning science (Driver, Leach, Millar, and Scott, 1996). Students' explanatory works have been referred to as their evidence of understanding. Some national education agencies, e.g., the United States of America, have suggested that explanation is a significant core practice to improve science teaching and learning (National Research Council, 2012; Pashler et al., 2007). Besides, Finland's core curriculum has proposed that explanation is one principal method for chemistry instruction (Finish National Board of Education, 2003). Those have indicated that: explaining is a significant behavior that science teachers should promote to 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' construction of 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 in four stages. The details are illustrated in table 1; herewith, the codes of theoretical-based design 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**<br>A hands-on group experiment about the galvanic cell, an electrochemistry content, is provided. This activity 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<br>The *Writing-Drawing on the Chemical-Electrical Representations* (WDCER) Worksheet (see the Appendix A): 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<br>The *Supporting Students' Understanding on Sub-microscopic phenomena* (SSUS) magnetic whiteboard: 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 | A03 A04 |

| Stage | Descriptions | Codes of theoretical based design |
|---|---|---|
| | experiment during stage 1. This media is made as a 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 chemical reactions. Moreover, students can use magic markers to write or draw some more symbols or pictures. This board is expected to be educational material as a scaffolding to assist students in learning 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 the stage that provides a chance for all groups of students to present their classroom experiment findings. They had to show ideas about the three representations: macroscopic, sub-microscopic, and symbolic. This stage 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 offered for every student: The Worksheet for *Supporting the Ability in Constructing Scientific Explanation* (SACSE): see the Appendix B. Designing this written scaffolding is based on the abovementioned models: CER and DN explanation models through logical deduction. Students need to do this paper individually, which is the third step of Vygotsky's internalization process. | 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 to provide opportunities for students: (1) Record the macroscopic as writing and drawing. (2) Draw some pictures for the sub-microscopic. (3) Write some alphabet to represent symbolic phenomena.

This galvanic cell experiment is expected to be the activities shown for all three representational phenomena during 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 to learn new science content because of the occurrence at the same time of such three phenomena. To assist students in learning electrochemistry more accessible, the idea of Lin, Son, and Rudd II (2016), therefore, has been referred to as the backing idea of teaching strategy. They look at the chemical representations as to the different concreteness and abstractness. This idea is displayed in the figure below.

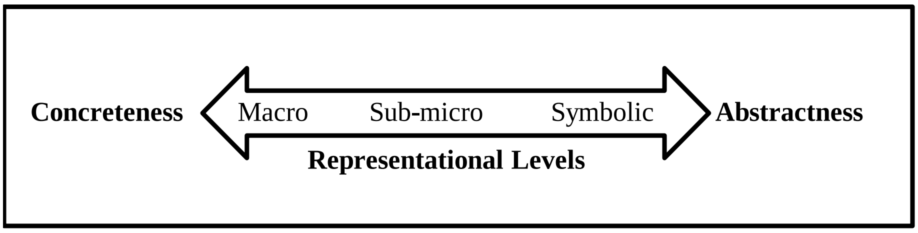



**Figure 1** The concept of three-level (macroscopic, sub-microscopic, and symbolic) chemical representations is clarified by concreteness-abstractness of phenomena

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 was moderate, and 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 the macroscopic first. They were assigned to do 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 (WDCER worksheet) was added to promote students' understanding of representing the sub-microscopic phenomena. Finally, learning about symbolic representation would be provided respectively.

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

A macroscopic representation can be observed simply more than the other two facets. Linking the concepts of sub-microscopic and symbolic phenomena to macroscopic at the same time 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. After completing a hands-on experiment, the SSUS magnetic whiteboard was given one board per group. 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 that support the human learning process. This idea believes that scholarly communication is essential in the classroom's teaching and learning. Communication may occur in many facets; however, a collaborative discussion is considered easy in the classroom because it can be conducted immediately if scientific issues arise during classroom learning activities. This collaborative discussion process for a student is provided in two dimensions: discussion with 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, capable peers and a teacher were set to be scaffoldings for bridging 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 the primary modes to express explanations as paper-based: the SACSE worksheet. This worksheet suggested a structure to promote students' expressing an explanation. For instance, the blank lines were provided for a written mode, while the blank boxes 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 with a general summary of an electrochemistry phenomenon. They need to add some more supporting details. Then, they need to give data and information as personal evidence to support that claim based on chemical representations, i.e., macroscopic, sub-microscopic, and symbolic. Finally, students must express their reasons for linking the evidence to that claim. This logical deductive way of explaining also accords to the CER model; it suggests that students begin proposing a 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 was 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 to construct explanations.

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

Johnstone' representations have been considered a significant influence on chemistry (Taber, 2013a; 2013b; Talanquer, 2011; Gilbert & Treagust, 2009) and also 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 the claims, 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. In order to link those evidence to the claims, 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' construction of scientific explanations in the electrochemistry of this study.

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

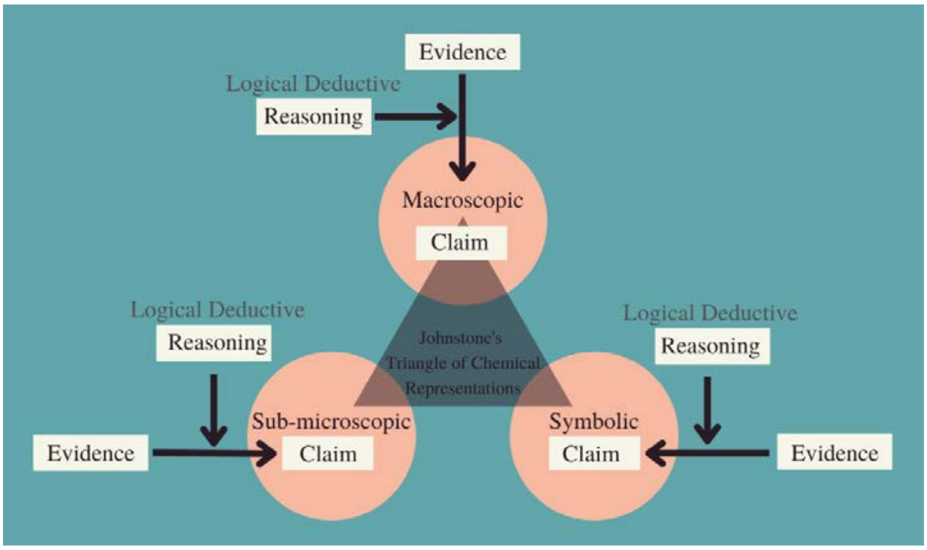



**Figure 2** Theoretical framework to measure students' scientific explanation ability using the multi-faceted content representations reinforces the DN and CER explanatory models.

**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 were assigned to do the classroom experiment at this stage; this activity can be illustrated as the external activity of the 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 by classifying the three representations as a personal assignment, the intrapersonal process. (3) transforming an interpersonal process into an intrapersonal one results from a long series of developmental events. This third step can be illustrated as stage 4 of 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 learnings (each group chose different chemicals or metals). Then, they must construct an explanation (stage 4) as a personal activity.

These three internalization steps are dialogues generated from personal inner speeches and thoughts; related to psychological and linguistic interactions (Bruner, 1962). This process is different from other kinds - cognitive and radical - of constructivism. Especially behaviorism that its approaches ignore the complexities of the internal psychological process (Wertsch & Stone, 1985), which is formed by each person's characteristics and experiences. However, the findings of this study would back up that this instructional strategy could encourage students' ability to construct scientific explanations of electrochemistry.

## METHODOLOGY

The reflective-based and 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 in the science classroom, including collecting the data and analyzing the classroom phenomena.

## 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). School 1 and School 2 students were same level of achievement ability because they 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 (50 minutes/period) through the four stages of this instructional strategy as shown in Table 1. 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 stages 1-3, 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 to explain the production of electric current from a redox (reduction and oxidation) reaction.

## 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 the Appendix C).

**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<br>Su: Sub-microscopic<br>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 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' worksheets for SACSE were scored to represent the ability to construct a scientific explanation for galvanic cells. Those scores as the categories of two schools are shown in table 3.

Table 3 shows that eight students could get a full score of the 2C-(3Ma-3Su-3Sy)E-4R category after learning this instructional strategy. In addition, 79.66% of all students scored more than 10 points (48 students: school 1 = 28, school 2 = 19), whereas merely 20.34% scored no more than 10 points (12 students: school 1 = 2, school 2 = 10).

Besides, students from both schools expressed their explanations in 22 categories: 11 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%) who still were not complete in providing fully.

According to the results of students' scientific explanations in table 3, the researchers and colleagues reflected on how to improve students' abilities. The reflection was developed through the after-teaching reflection, students' tasks, and student interviews. This reflection allowed us to learn what and how to increase students' scientific explanation ability in learning about galvanic as following issues.

**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**

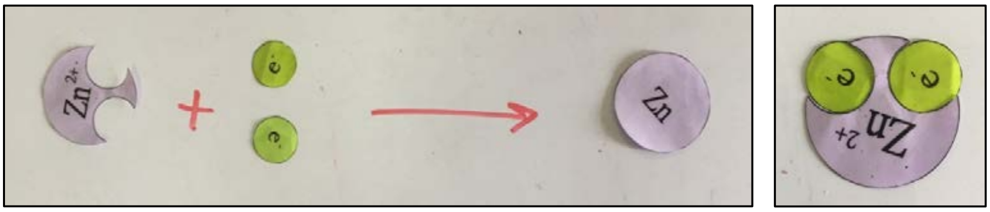
The teaching about galvanic in two schools suggested that the researchers learn some issues for improving students' scientific explanation ability. These included:

- Improving the sub-microscopic media via the atomic and ionic sizes-based design
- Pictorial sub-microscopic evidence for supporting scientific explanations
- Adjusting the stages of the instructional strategy

Each issue will be discussed below.

*Improving the sub-microscopic media: via the atomic and ionic sizes-based design*

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.



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

In figure 3, A student (Sc1No06) described his/her group magnetic whiteboard: (1) *"this dented atom of zinc gains 2 electrons; it will become a full atom like this"*. (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 is like a frog"*. This sentence made everyone laugh, including a reflective peer. However, as the teacher roles, the first author realized that this might form 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 with 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, the sub-microscopic (SuE) was the lowest average mean score compared to other elements, see table 4 and figure 4. This lack indicated that there were some problems in this element.

**Table 4** School 1's scientific explanation ability mean scores, standard deviations, and percentage compared to the full scores of each element

| Elements | C | E | | | R |
|---|---|---|---|---|---|
| | | MaE | SuE | SyE | |
| Mean | 2.00 | 2.73 | 2.23 | 2.97 | 3.10 |
| (SD) | (0.00) | (0.58) | (0.73) | (0.18) | (0.66) |
| %* | 100 | 91.11 | 74.44 | 98.89 | 77.50 |

%* = Percentages compared to the full scores of each element
SD = Standard deviations

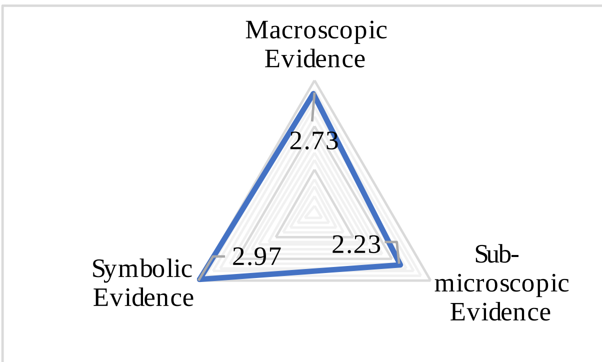



**Figure 4** School 1's scientific explanation ability mean score of macroscopic, sub-microscopic, and symbolic evidence

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

Regarding sizes and radii, almost all elements in senior 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 sizes that would increase when gaining electrons and decrease when losing electrons. A sample of the model sheets is illustrated as actual sizes for A4 paper printing; details are in figure 5.

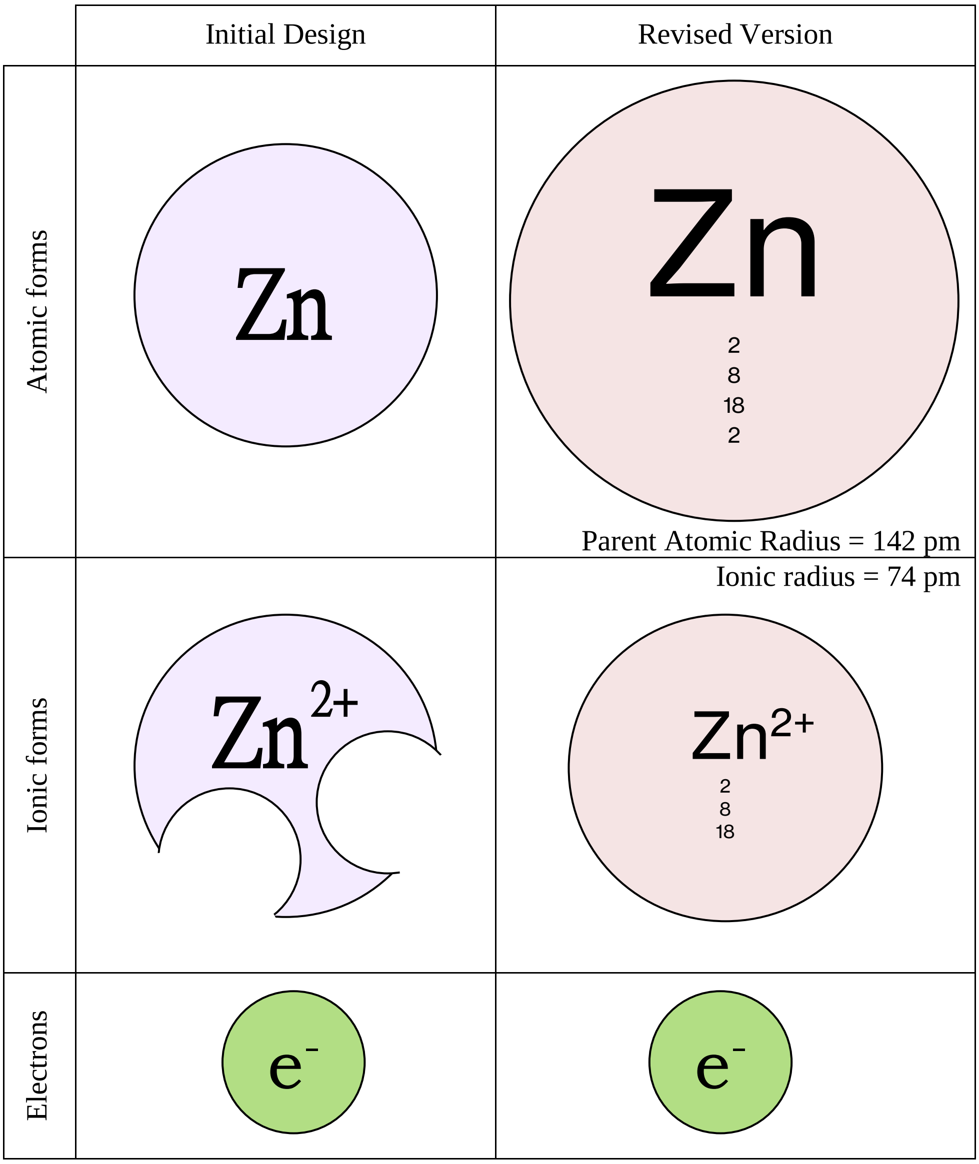



**Figure 5** The atomic and ionic model sheets that are adjusted based on the concept of atomic size and radii, and electron configuration. (Real sizes for A4 paper printing)

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 that each is different. In this design, 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 (green) 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 142 Picometers which is bigger than the ionic radius of $Zn^{2+}$: 74 Picometers [LibreTexts.org: Brown, LeMay, Bursten, Murphy, & Woodward (2022)]. Moreover, both forms have been added to their simple electron configurations to clarify the number of electron shells or energy levels.

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 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, 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.

After employing this revision of model sheets for use in the SSUS magnetic whiteboard, the school 2 students' sub-microscopic misconceptions were not found during either the observation or reflection steps of the action research process.

Besides, in stage 2 of this instructional strategy, a concept of the different sizes of ions and their parent atoms appeared in the WDCER worksheet. Students represented the electrochemical phenomena by displaying the electron transferring both anode and cathode, which is related to the size-changing of particles. The sample is shown in figure 6, which is the work of a Sc2No12 student.

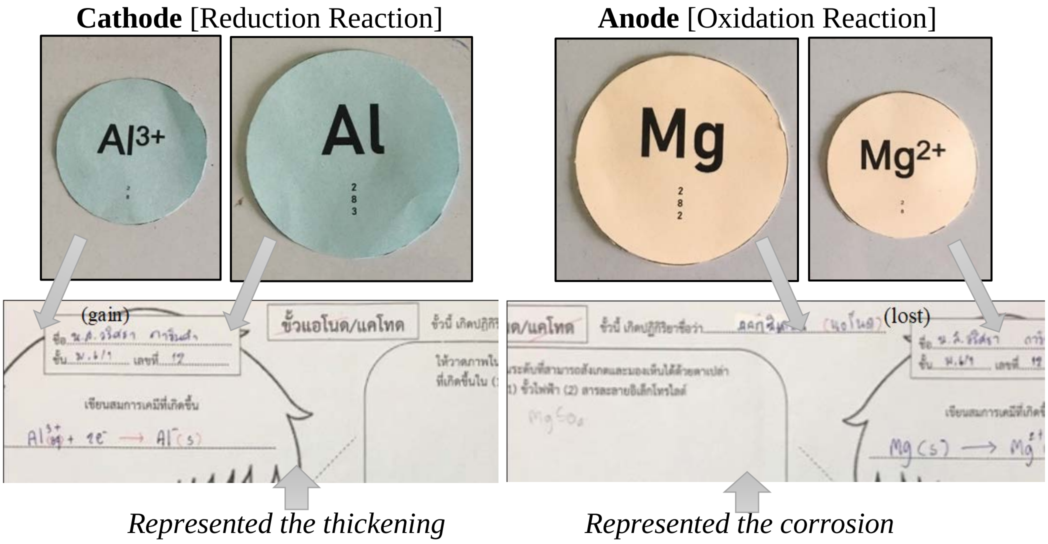



**Figure 6** The Sc2No12 student's using the concept of the electron configuration from the revising version of model sheets to link macroscopic to sub-microscopic phenomena.

In figure 6, a Sc2No12 student got 14 points for 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 was the reduction reaction by illustrating a puffed area; see a bottom left arrow. S/he drew five or six small circles to represent an area of aluminum metal dipped in the electrolytic solution thicker than before they started the experiment, which is a macroscopic phenomenon; they experimented with in stage 1 of the instructional strategy. Based on scientific data, $Al^{3+}$ ions in the liquid electrolytic solution of aluminum sulfate [$Al_2(SO_4)_3$] gain three electrons, becoming the solid state of aluminum metal. 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 a vertical ellipse around the simple electron configurations of each: $Al^{3+}$ = 2 8

and Al = 2 8 3 respectively. [Note: However, there is a misconception about the number of losing electrons which is $3e^-$, should not be $2e^-$ like s/he wrote].

(2) The magnesium metal's *corrosion* in the anode was the oxidation reaction; see the bottom right arrow. S/he made a hole in a group of small circles to represent a dented area of aluminum metal dipped in the electrolytic solution. This metal corroded, a macroscopic phenomenon they experimented with in stage 1. Based on scientific data, the magnesium metal [Mg(s)] lost two electrons, becoming $Mg^{2+}$(aq) ions; all are in the liquid electrolytic solution of magnesium sulfate [$MgSO_4$]. These can be written as a chemical reaction as [Mg(s) → $Mg^{2+}$(aq) + $2e^-$] which s/he could write correctly. Both $Mg^{2+}$(aq) and Mg(s) were represented by marking a vertical ellipse around the simple electron configurations of each: $Mg^{2+}$ = 2 8 and Mg = 2 8 2, respectively.

These findings that students applied the concept of atomic/ionic sizes, the electron configuration, and the flow of electrons to clarify the occurrences of electric current have indicated the benefits of the SSUS whiteboard as a scaffolding media to encourage students' learning in a sub-microscopic phenomenon. These accord with the study of Berg, Orraryd, Pettersson, & Hultén (2019), which assigned students to make physical models of sub-microscopic particles for equitable chemical reasoning.

We would propose that this educational media's new design could benefit students to understand the scientific phenomena of the size-changing of an atom and its ion more closely. Also, it has significantly played a role as a tool to assist students can represent the particle levels as the sets of evidence to support their explanations. Hence, the students' sub-microscopic evidence would be focused on.

*Pictorial sub-microscopic evidence for supporting scientific explanations*

After we finished all three periods of the four stages of the instructional strategy, SACSE worksheets (details were in table 1 and Appendix B) from all 59 students were analyzed on their sub-microscopic evidence. Findings are shown in table 5.

In table 5, 50 students (84.75%) represented their ideas of sub-microscopic by making the pictorial mode and the written mode: the major group. In comparison, 9 students (15.25%) used the inappropriate pictorial mode to support their scientific explanations: the minor group. In the minor group, 3 students made inappropriate pictures but were good at writing, and 6 showed inappropriate evidence in both pictorial and written modes. We did not find students expressing their sub-microscopic ideas by a single mode of writing or drawing.

Comparisons of average mean scores of explaining ability between two groups of students who illustrated sub-microscopic evidence by (1) using pictorial mode and (2) using inappropriate pictorial mode were shown in figure 7.

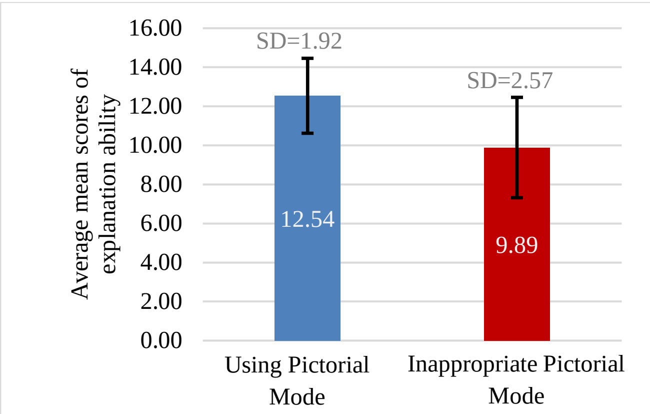



**Figure 7** Average mean scores and standard deviations (SD) of the explanation ability divided by two group of students who illustrated sub-microscopic evidence by (1) using pictorial mode and (2) making inappropriate pictorial mode

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

| Types of Pictorial Sub-microscopic Evidence | | | Scores | Categories | F Sc 1 | F Sc 2 | Total (%) | Grand total (%) |
|---|---|---|---|---|---|---|---|---|
| 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 | 59 |

n/a = Not Available, F=Frequencies of Students, Sc.1=School 1, Sc.2=School 2

In figure 7, we found that a group of students who made sub-microscopic evidence using pictorial mode (mean = 12.54, SD = 1.92) got higher average mean scores than those who made inappropriate pictorial mode (mean = 9.89, SD = 2.57). This comparison indicates that representing phenomena by drawing pictures supports students' ability to construct a scientific explanation of the galvanic cell content. This finding accords with the studies of Areljung, Skoog, and Sundberg (2022), Tyler, Prain, and Hubberm (2018), and Ainsworth, Prain, and Tytler (2011), that proposed the advantages of drawing pictures to represent scientific concepts.

In addition, analyzing a major group of 50 students who made pictorial mode, we found five types of sub-microscopic representation arranged from highest to lowest percentages.

I. Chemical Equation pictorial: 15 students (25.42%) with 5 categories.
II. Dynamic pictorial: 15 students (25.42%) with 9 categories.
III. Macroscopic pictorial: 8 students (13.56%) with 5 categories.
IV. Dynamic + Macroscopic pictorial: 7 students (11.86%) with 6 categories.
V. Notational pictorial: 5 students (8.47%) with 4 categories.

The details and samples of each type are illustrated in table 6.

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

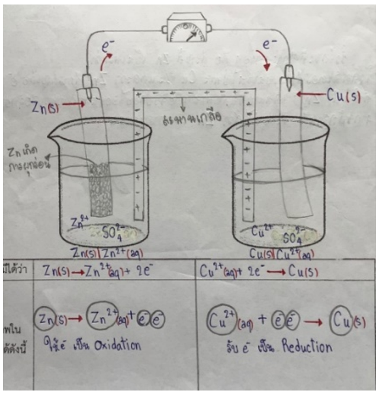
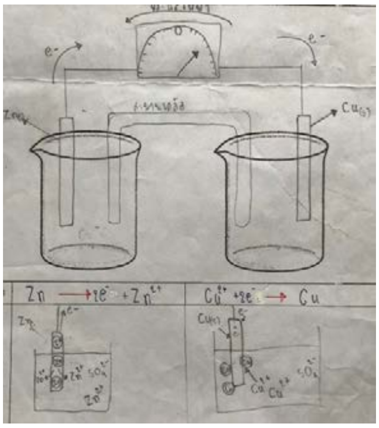
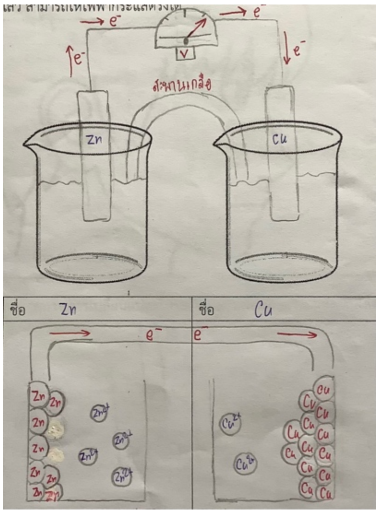
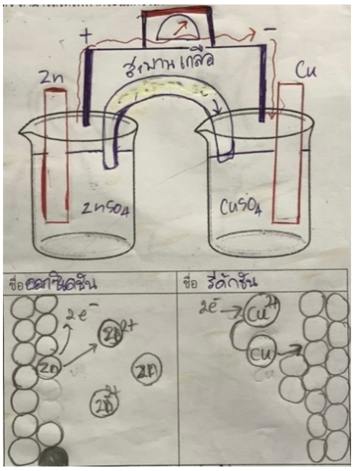
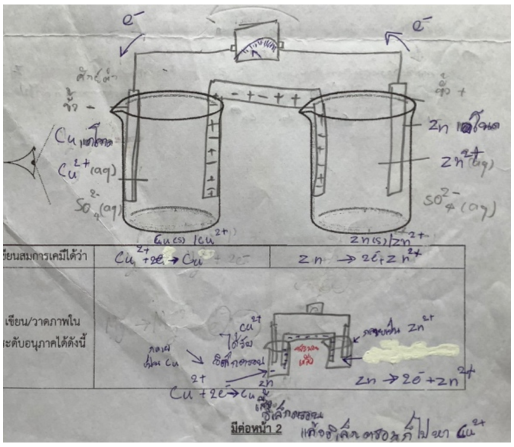
| **Types of pictorial sub-microscopic evidence** | **Descriptions** |
|---|---|
| I. Chemical Equation pictorial   | **Sc1No23**:<br>2C-(3Ma-3Su-3Sy)E-3R=14<br><br>Students expressed sub-microscopic evidence by drawing circles to represent atoms and ions as a chemical equation of two reduction and oxidation reactions. That chemical equation is one of symbolic form, i.e., students represented sub-microscopic ideas by symbolic. |
| II. Dynamic pictorial  | **Sc1No33**:<br>2C-(3Ma-3Su-3Sy)E-4R=15<br><br>Students made sub-microscopic evidence by drawing arrows to show the flow of losing and gaining electrons of the anode and cathode, respectively. In addition, some circular symbols of atoms and ions also were shown to clarify their ideas. |

**Table 6** (Cont.) Samples of five types of pictorial sub-microscopic evidence

| Types of pictorial sub-microscopic evidence | Descriptions |
|---|---|
| III. Macroscopic pictorial<br><br> | **Sc2No01**:<br>2C-(3Ma-3Su-3Sy)E-2R=13<br><br>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. |
| IV. Dynamic + Macroscopic pictorial<br><br> | **Sc2No03**:<br>2C-(3Ma-3Su-3Sy)E-4R=15<br><br>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<br><br> | **Sc1No06**:<br>2C-(3Ma-3Su-3Sy)E-4R=15<br><br>Students of this group used a 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. |

These findings of the five different types of students' making sub-microscopic evidence can emphasize the importance of several kinds of learning styles. Personal methods to make the meanings of natural phenomena are formed from prior knowledge and experiences. If science educators and teachers understand the student's individual differences and the contexts of each school, it would be effective in learning science (Tobin & Tippins, 1993). Therefore, the stages of this instructional strategy have also been adjusted to fit classrooms' occurrences as phenomenological-based designs.

*Adjusting the stages of the instructional strategy*

In stage 1 of the instructional strategy, students must experiment without fixed directions. Each student's group could independently design to pair any kinds of 4 metals: aluminum, copper, magnesium, and zinc, to their appropriate electrolytic solutions (we provided more than four kinds). If an electrolytic solution is inappropriate for its metal, the reaction might not happen.

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

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, see table 1. However, the Share Ideas between Group Discussions stage occurred during stage 1: Learn through Macroscopic Phenomena because of the wrong selections of electrolytic solutions.

This classroom occurrence pointed out the overlapping of stage 3 with others. We would argue that sharing ideas can be conducted at any stage because students learn in the same room where each group can see each other. The process of sharing ideas can generally occur; students have already known results from other groups all the time naturally. Thus, the Revised version of the strategy would be proposed together with the Original version; details are in figure 8.


**Figure 8** Original and Revised versions of the instructional strategy

In figure 8, stage 3 of the Revised version has been added in every other stage, making this instructional strategy more flexible. Teachers' teachings and students' learnings should be adaptable activities; the contexts are essential. Science educators and teachers can employ any version of the strategies depending on their classroom situations. This adjusting of the instructional strategy accords to some research that changed their pedagogy based on contexts, such as the study of Commons (2007), which changed the teaching methods in several aspects to improve students' learning to read. In addition, Ghosh (2022), Luik and Lepp (2021), and Carroll, Chaparro, Rebensky, Carmody, Mehta, and Pittorie (2021) have adapted and adjusted their teaching strategies for different groups of students during the COVID19 pandemic. Immediately context-based adjusting the strategies during teaching can support students in constructing scientific explanations for electrochemistry.

## Conclusions

The purpose of this study is to assist students can construct their explanations of electrochemistry that have been indicated as complicated content. Therefore, the teaching strategy was developed from the philosophical ideas that were warranted through research conduct and had to be in credible publications. The strategy was planned and split into sub-stages to make it easy to implement in classrooms. Also, the educational pieces of stuff (worksheets, whiteboard, model sheets, laboratory equipment) were designed and developed based on theoretical backgrounds in order to support students could reach the scientific phenomena they should understand. They would bring their understanding of those phenomena to construct an explanation based on their academic experiences.

This study has developed a method to measure the students' explanation ability (see table 2). This method was formed based on the well-known theories that came from reviewing the literature. The product from this measurement has been displayed in the categories. Each category consists of five sub-components of the explaining ability. In addition, these categories would have a score that fits students personally; the score can benefit teachers to understand their students more profoundly. Another unique property of this measurement is that although some students got the same score, they may have different components. Teachers can effectively use this data to analyze students' abilities, leading to educational success because explaining natural phenomena is the main aim of learning science.

This study found the importance of using pictorial and written modes as evidence that supports students' explanation ability. In addition, several types of students' expressing sub-microscopic ideas have indicated the students' differences, and several kinds of learning styles should be concerned by chemistry teachers and educators.

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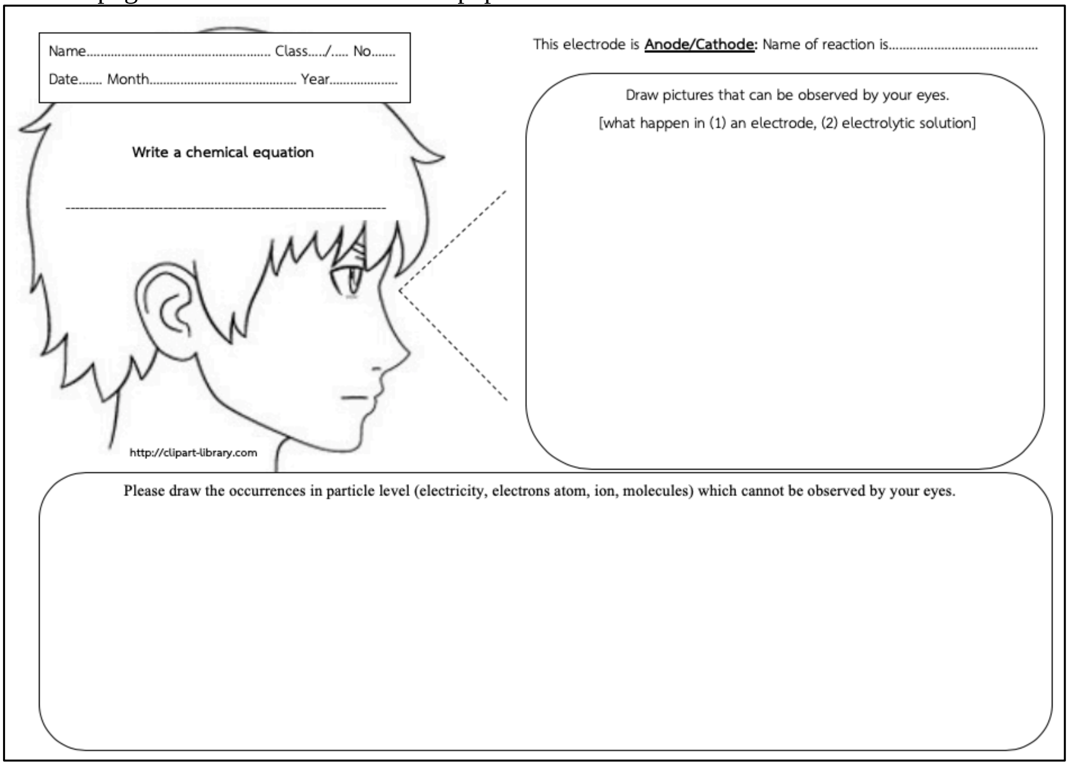
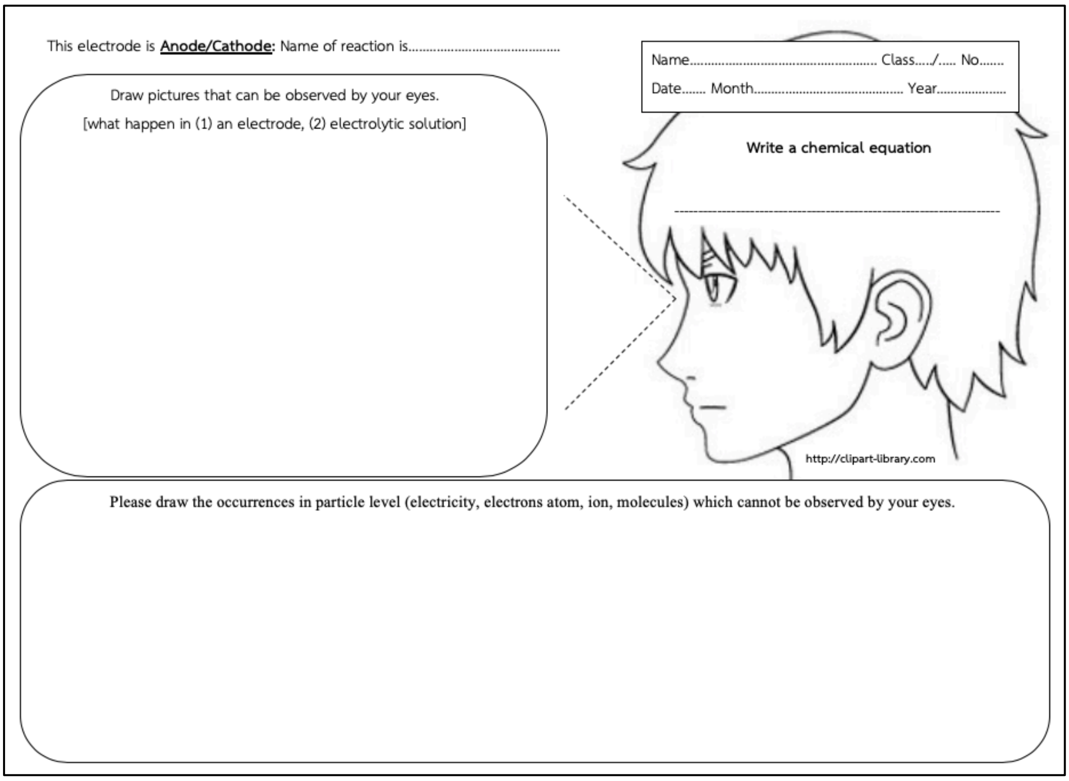
**Appendix A**

The Writing-Drawing on the Chemical-Electrical Representations (WDCER) Worksheets

The left page: The actual size is A4 size paper.




The right page: The actual size is A4 size paper.



**Appendix B**

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

**Worksheet for supporting the ability in constructing scientific Explanation**

**(SACSE)**

Name...................................................................... Class...../..... No......

Date......... Month.......................................................... Year...............

**Please** write and draw any things can help you construct an explanation about: if we connect two half-cells $Cu(s)|Cu^{2+}(aq)$ and $Zn(s)|Zn^{2+}(aq)$, can we produce the direct electric current? Please make ✓ into ☐

**Answer:** ☐ CAN produce ☐ CANNOT Produce

| | | |
|---|---|---|
| Names of half-reactions | | |
| write/draw evidence in particle level | | |
| Chemical equations | | |
| A balance equation | | |

**Tips & Tricks**: your explanation should contain
1) Evidence and Reason that can be observed by eyes
2) Evidence and Reason that cannot be observed by eyes
3) Evidence and Reason in symbolic forms

How can you provide **reasons** to link a conclusion and pieces of evidence? (Why the connecting of two half-cells can produce the direct electric current?) Please explain explicitly.

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**Appendix C**

Content Specific Rubric Scores for Examining Scientific Explanations: Galvanic cell

**Claim**

| Credit | Level | Answer | Clarification |
|---|---|---|---|
| 2 | Correct Claim | Can produce the electric current | Students mark ✓ symbol in the blank ☐ |
| 1 | Alternative Claim | Cannot produce the electric current | 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 evidence | Provides<br>1) The corrosion of Zn(s)<br>2) The thickening of Cu(s)<br>3) Moving of needle direction of voltmeter (direct to copper metal)<br>by writing and/or drawing | Draw atomic/particle level pictures and/or write as notation that show Zn(s) atoms lost 2 electrons and becoming $Zn^{2+}$(aq) or $Cu^{2+}$(aq) gained 2 electrons becoming Cu(s) | Write two chemical equations of<br>1) An oxidation reaction which losing electrons<br>2) A reduction reaction which gaining electrons |
| 2 | Partial level of evidence | Provides 1 appropriate pieces of evidence | Draw and/or write atom/particle level but incomplete | Write chemical equation of electron transfer but incomplete |
| 1 | Alternative level of evidence | Provides only inappropriate macroscopic evidence (or non-chemical principle) | Draw and/or write only inappropriate particle level of evidence (or non-chemical principle) | Write alternative chemical equation of electron transfer (or non-chemical principle) |
| 0 | No evidence | Provides nothing | Provides nothing | Provides nothing |

**Reasoning**

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

SEAT

# IJSET

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