2024
SciEd
SEAQIS Journal of Science Education
SEAQIS Journal of Science Education (SciEd)
ISSN: 2987-8101 | E-ISSN: 2964-7533
Vol: 4, No: 1, PP: 54-70
www.journal.qitepinscience.org
Research Paper
Open Accsess

Patterns of Metacognitive Levels in Chemistry Problem-posing

Benny Yodi Sawuwu

SMA Katolik Santu Petrus Pontianak, West Kalimantan, Indonesia
Corresponding author, e-mail: benny@smapetrus.net

Abstract

This study aims to describe the patterns of metacognitive levels in chemistry problem-posing activity of 76 undergraduate students from the Chemistry Education Department of Yogyakarta State University. Chemistry articles used in this investigation and the chemistry problems were classified based on the taxonomy of chemistry problem-posing skills where problems were later classified into seven metacognitive levels. Semiotic analysis was conducted to find the meaning of the signs found in the chemistry problems. This data analysis used and modified the three steps of the semiotic analysis with a phenomenological reduction method. Chemistry problem-posing in this current study shows the flow of the formulation for each problem. The input aspect for the formulation determines the process and the output result. The seven patterns are sorted into four participant types in submitting the chemistry problems: planning error (for poor, fair, and low intermediate level), evaluation error (for intermediate level), the imbalance metacognitive (for high intermediate and excellent level), and balance metacognitive (for outstanding level). The higher the level, the more complex and multiperspective determinations used for arranging a chemistry problem.

Keywords: Developed fundamental skills; Practical work; Laboratory; Student's performance

Introduction

Some studies about either question posing skills or problem-posing skills in chemistry that have been conducted, exposed the cognitive level in general and analysed the metacognitive level in a few (aramustafaoglu, et al., 2003; Blonder, et al., 2008; Demirdogen & Cakmakci, 2014; Gillete & Sangers, 2014). However, when students read the chemical reading as the precursor to problem-posing, they experienced both cognitive and metacognitive strategies (Khezrlou, 2012; Korpershoek, et al., 2015; Leopold & Leutner, 2015). This shortcoming is an effect of the difficulties to observe metacognitive aspects since all processes occur in the mind (Dunlosky & Metcalfe, 2009; Norris & Phillips, 2012; Grotzer & Mittlefehldt, 2012; Schraw, et al., 2012).

A think-aloud protocol could be the way to explore the metacognitive process (Ben-Eliyahu & Bernacki, 2015; Binbarasan-Tüysüzoglu & Greene, 2015). The advantage of this protocol is to give the outlook of both the memory work process and the actual thinking process when one is reading, understanding, strategizing, processing, and deciding (Wilhelm, 2001; Charters, 2003; Overton, et al., 2013). Particularly in chemistry reading comprehension, questioning the readers could be the indicator to estimate their understanding about chemistry in the reading context metacognitively (Herscovitz, et al., 2012; Kaberman & Dori, 2009a; Ghasempour, et al., 2013). Nevertheless, taxonomies used on some explorations depend on the variables of the parameters used (Herscovitz, et al., 2012; Kaberman & Dori, 2009b; Smith, et al., 2010; Pappa & Tsaparlis, 2013) to focus on a specific treatment (Bruck & Towns, 2009; Undersander, et al., 2017) and measure the cognitive to the metacognitive aspects

(Demirdogen & Cakmakci, 2014; Sanabria-Rios, D.; Bretz, 2010; Stickles, 2011), as it becomes a problem for teachers or assessors to determine their students' chemistry problem-posing skills metacognitively.

A semiotic analysis was selected to cover the problems above. This semiotic analysis could expose the meaning of the signs (Radford, 2000; Tang, et al., 2014), and how the signs express thinking processes especially in chemical thinking (Liu & Taber, 2016). The signs are meant as signifiers for the problems that students pose as a result of their metacognitive thinking process. Through this analysis, we can have a way to find the metacognitive processes on each problem posed qualitatively.

This current study is the advanced research of the chemistry problem-posing taxonomy by Sawuwu (2018) who classified chemistry problem-posing into seven metacognitive levels. Further explanations are needed regarding problem-posing patterns to help users classify metacognition levels based on the taxonomy. Following the phenomenological reduction technique by (Chopra, et al., 2017), this current study will analyse the textual data of chemistry problem-posing to find patterns used by participants in generating the problems. This study aims to describe the patterns of metacognitive levels in chemistry problem-posing activity based on the taxonomy.

Methodology

2.1. Participant

The participants for this qualitative research are undergraduate students who have received the Chemical Equilibrium course at the Chemistry Education Department, Faculty of Mathematics and Natural Sciences, Yogyakarta State University, for the 2017/2018 academic year and are selected according to the following criteria: (a) the time span between having completed the topic of chemical equilibrium with the shortest test time to avoid random errors, and (b) students taking the test voluntarily to avoid the type of reader who was driven by obligation test (obligated reader). A total of 181 students from the Department of Chemistry Education (Chemical Sciences and Chemistry Education Study Program) FMIPA UNY for the academic year 2017/2018 (from Chemistry Education [CE] and Pure Chemistry [PC] programmes) matches the criteria (a), but only 110 students who could meet criteria (a) and (b). After being given the test, the remaining 99 participants whose data can be processed after being selected cannot determine the dominant reading technique they did. Then it was found that only 76 participants submitted one problem based on the test order and fulfilled all the other test conditions.

2.2. Instruments

The test instrument design was named the Metacognition Explorator in Chemical Equilibrium Problem-posing Skills. This instrument consists of a checklist of metacognitive activities during the test, articles on the skills of posing a chemical equilibrium problem, a problem-posing sheet, and a self-assessment sheet to determine the perceived performance of the participant's test. The characteristics and indicators of this instrument set are derived from previous qualitative studies (Sawuwu, 2018). Chemical articles used in the qualitative studies were compiled based on four components of chemical article structure (Herscovitz, et al., 2012), four types of chemical representations (Gilbert & Treagust, 2009a; Kaberman & Dori, 2009a, 2009b), four levels of humanistic approaches in the chemistry education tetrahedral (Sjostrom, et al., 2016), and three characteristics of scientific reading (Norris & Phillips, 2012). Through the think-aloud process, metacognitive reading patterns, and chemical problem-posing activities carried out by participants (in previous studies), six specific aspects were found to perfect the characteristics of the metacognitive stimulating chemistry article as shown in Table 1. Aspects of test instructions and article identity were used as the basis planning and readers' stimulation for the chemistry articles they will read. Aspects of the structure of the article and presentation of chemical representations are used to build the framework of chemical articles which become the main characteristics of chemistry reading and chemical understanding used in reviewing the chemical information provided. Aspects of the humanistic approach and the nature of chemistry articles are used to test the content of chemistry readings against the demands of 21st-century chemistry learning and the transfer of knowledge from chemistry readings to readers. The actual performance of participants' chemical equilibrium problem-posing skills was obtained from the assessment of the problems submitted based on the taxonomy of chemical problem-posing as shown in Table 2.

According to the four parameters above, the classification of the chemical problem-posing skill was determined by the attainment in each parameter. The level is converted to the score of each parameter. The sum of all scores is classified into seven categories as shown in Table 3.

Table 1. Characteristics of The Chemical Article.

No.	**Characteristics**	Description
1	Title	Indonesia: *Kesetimbangan Karbonat dan Rusaknya Terumbu Karang* English: Carbonate Equilibrium and Coral Reef Damage
2	Word and chemical representation	Word count 623 words; Two chemical equations = 15 words; A phenomenological picture = 39 words; An image (dependent multi-representation) =105 words
3	Text structure/paragraph	Socio-scientific issues of Minister Susi's policies and coral reef damage Definition of coral reefs and their constituent components Seawater provides carbonates Seawater acidification process Effect of acidification in chemical equilibrium perspective Effects of trash and fish bombing
4	Keywords	Indonesia: *asidifikasi air laut, kalsifikasi terumbu karang, kesetimbangan karbonat* English: seawater acidification, coral reef calcification, carbonate equilibrium
5	Independent representation	Coral reef damage (phenomenology); Acidification reaction (symbolic)
6	Dependent multi-representation	Coral reef calcification reaction (process-phenomenological-symbolic) Carbonate equilibrium reaction (process-phenomenological-symbolic)
7	Socioscientific issues	Coral reef maintenance as a policy of the Ministry of Marine Affairs and Fisheries of the Republic of Indonesia
8	Contextual	Sociochemistry: the importance of coral reefs for the future of the earth Historichemistry: the impact of the industrial revolution on the future of coral reefs
9	Critical	Opens the reader's mind to pay attention to the preservation of coral reefs and the potential for overcoming them
10	Iteration	Requires repeat reading and decreasing reading rate on the seawater acidification process segment and its effect on carbonate equilibrium and coral reef calcification.
11	Interactive	Multi-representation = text and images for the acidification process of seawater Persuasive = in the last sentence of the first and last paragraph
12	Principled	Contains one topic of thought, namely the balance of carbonates in the ocean and their effects on coral reefs.
13	Interdiscipline	Chemical equilibrium, biogeochemistry, maritime chemistry, biology
14	Intradiscipline	Chemical equilibrium, reaction rate, alkalinity, acid-based solution, salt hydrolysis
15	Reference	Primary sources: 9 journals Secondary source: a national news site

Table 2. Parameters in The Taxonomy of Chemistry Problem-posing Skill.

Parameter	**Thinking level (TL)**	**Problem Structure (PS)**	**Chemical understanding (CU)**	**The Precision of The Chemical Concepts (CC)**
Signifier	the analysis of question word	The components of the problem posed	The use of chemical representation	the relationship of each information constructing the problem
Score 1	Failure	Posing nothing	Non-representation	Error (out-context)
Score 2	Definition	Posing a statement	Definition-unirepresentation	Misrequirement (failure in posing problem)
Score 3	Explanation	Posing a single question	Exploration-unirepresentation	Misconception (failure in preliminary knowledge)
Score 4	Exploration	Posing a coordinated question	Exploration-birepresentation	Misunderstanding (failure in understanding the chemistry aspect in the text)
Score 5	Expansion	Posing a simple problem	Correlation-birepresentation	Misrepresentation (failure in linking the chemistry concepts)
Score 6	Complex	Posing a complex problem	Multi-representation	Correct (Correct in linking the other concept to explain the chemical concept in the article)

Table 3. Classification of The Chemical Problem-posing Skill**.**

The Sum of All Scores	**Category**	**Signified**
22 ≤ total ≤ 24	Outstanding	The chemical problem is significantly in metacognitive level
19 ≤ total ≤ 21	Excellent	The chemical problem is lack of monitoring
16 ≤ total ≤ 18	Higher intermediate	The chemical problem is lack of the representations
13 ≤ total ≤ 15	Intermediate	A problem and a question are indiscriminate
10 ≤ total ≤ 12	Lower intermediate	The in-context chemical understanding is required
7 ≤ total ≤ 9	Fair	The understanding about the problem components is required
4 ≤ total ≤ 6	Poor	The task understanding is required

2.3. Analysis

Problems posed by participants were analysed based on the taxonomy (Table 2). Then, the problems were classified into seven metacognitive levels based on Table 3. The semiotic analysis was conducted to find the meaning of the signs found in the chemical problems. This data analysis used and modified the three steps of semiotic analysis (for finding the signifier-signified relationship) with a phenomenological reduction method.

The first was an initial analysis that was the re-representation of the problems. The problems posed by the students were used as the particular signs in this analysis. Problems were identified according to its components: initial state (the data), final state (the goal), and operator (the limitation or possible ways to bridge the data problem to the goal). Chemical representations of the problems were also identified in the phenomenological, symbolic, model, or process representations. The second was the semiotic affordances. In this second phase, the first identification was on the question words they used in their final states as the signifier. The transcriptions about the problem-posing activities were used to reveal the meaning of the question words for each participant (to find why students used the question words). The meaning found was encoded to a semiotic expression. Every code was collected for each theme and was undertaken a second-cycle coding. The second identification was determined from the various expressions of each code in the first identification, so it was also for the next identification. The identification was terminated when the parameter found was estimated to complete the shortcomings of the previous parameter. The third was the iterative nature of the analysis. Comparing the analysis of patterns was conducted to have a consistent meaning for each signifier found. After each signifier had its own signified meaning, the themes were sorted ascendingly toward the complexity of the signified thinking towards the taxonomy.

A phenomenological reduction method was used to analyse the problems posed. All data was then reduced (horizontalization of data). After this reduction, the data was encoded and categorised in the same theme that represents the specific expressions and findings towards the metacognitive processes in the problems. The coding from the patterns were used to find neomatic themes (what the phenomenon is) and the coding from the semiotic analysis was used to find neosis themes (how the phenomenon is). Then, data verification was conducted to clarify and reinforce the themes. The neomatic themes were unified as a formulation of the textural definition and the neosis themes as the structural definition. By blending the textural and structural definitions and adding data interpretations, the themes were merged to be the essential definition of each pattern.

1. Results and Discussions

3.1. Pattern of The Chemistry Posing Activities of Each Metacognitive Level

The semiotic analysis of previous studies showed the classification of metacognitive levels based on the signifiers contained in the problems posed by participants. However, this present study can reveal the process of problem-posing chronologically. This process will help analyse and find the causes of low-level metacognition. If in previous studies the discussion of stages of chemistry problem-posing activities is separated from the chemistry problem-posing analysis, this current study will parallelise the pattern analysis in the five stages of chemistry problem-posing process and simplify them into an input-process-output diagram.

a. Poor level

The pattern of the problem-posing process for participants in the poor or very low category is shown in Figure 1. This pattern does not result in chemical problems. This is observed in the PC031 participant problem submission sheet as follows.

"Fishing with dynamite can kill shellfish because dynamite can destroy the calcium carbonate skeleton."

If the proposed statement is analysed (PS: 1), it is found that the statement is not in accordance with the test instructions (TL: 1), does not focus on the context of chemical equilibrium discussed in the article (CC: 2), and only examines phenomenological representations. (CU: 2).

Input: → **The chemical problem is the conclusion of a chemistry article.**	**Process:** **1) Find the object of phenomenology of chemistry. 2) Find cases about the chemical object.** →			**Output:** **Rewrite the news sentence about the chemical object of the phenomenology.**
Initiation	*Metacognitive reading*	*Problem determination*	*Writing the problem*	*Termination*

Figure 1. Pattern of the poor level in the chemistry problem-posing activity.

The poor level in the previous taxonomy (Sawuwu, 2018) signified that participants needed task understanding. From Figure 1, the pattern indicates that the statement posed is not a question but just a repetition of information.

b. Fair level

The pattern of the chemical problem submission process for the fair or low category is shown in Figure 2. Slightly superior to the very low level which does not pose a problem, this level is able to recognize the limits of the required chemical problems. This is observed from the PC042 participants' problem submission sheet as follows.

"The increase in CO_2 in the atmosphere has an impact on coral reefs. The availability of $CaCO_3$ is influenced by the carbonate balance in the ocean."

The analysis of the proposed statement (PS: 1) is not in accordance with the test instructions (TL: 1). Two types of chemical representations were used, namely phenomenology and process, but no relationship was found between the two (CU: 4). Although the first sentence is correct, the second sentence gives rise to a different interpretation of the phrase "availability of $CaCO_3$" because it does not show a relationship in the context of the previous sentence. This phrase can express a misunderstanding (CC: 3) that carbonate equilibrium is a source of $CaCO_3$ or $CaCO_3$ is produced from the sea.

Input: →	Process: →	Output:
1) The chemical problem is the conclusion of a chemistry article. 2) The problem is limited to the concept of chemical equilibrium in chemistry articles.	Find chemical objects with chemical characters that match the problem constraints (such as chemical formulas, chemical quantities, and chemical symbols).	Paraphrase the statement about the case of the chemical object.
Initiation	*Metacognitive reading* — *Problem determination* — *Writing the problem*	*Termination*

Figure 2. Pattern of the fair level in the chemistry problem-posing activity.

The fair level in the previous taxonomy (Sawuwu, 2018) signified that participant needed understanding of components in a problem. Figures 1 and 2 indicate similar output but this second pattern is just a paraphrase of information.

c. Lower intermediate

Three patterns of the chemical problem submission process were identified in the lower intermediate category as shown in Figure 3. Type A did not ask question sentences as shown in the following PC051 participant problem submission sheet.

Type A: *"Increased CO_2 in the atmosphere results in more CO_2 soluble in water. The increase in CO_2 are caused by many things such as global warming, dynamite fishing, and many more. This will destroy the carbonate balance causing the $CaCO_3$ to be unsaturated, causing algae lessening and coral reefs bleaching. Problems: (a) CO_2 is more soluble in water; (b) the greenhouse effect and global warming; (c) shifting of carbonate equilibrium."*

Type B: *"If there is more CO_2 in the atmosphere/unexpectedly then in what year will it not form in the polar regions? Coupled with other factors that further aggravate the marine ecosystem."*

Type C: *"Indeed, if you look at Indonesia as a country that has wide waters, wide seas. But the citizens themselves do not / less attention to the Indonesian sea. And it is undeniable that the whole world must emit large amounts of CO_2. Then, to overcome this, what should be done?"*

Even though Type A was only a sentence stating the initial state (TL: 1 and PS: 1), participants used two chemical representations (phenomenology and process) which were correlated. However, the participant misunderstood (CC: 3) that blasting fishing is a factor that destroys the carbonate balance and acidification that causes coral bleaching.

Types B and C ask single question sentences (PS: 3). Type B tends to ask as a formal action that does not need to be explained (TL: 2) and the answer can be found explicitly in the article, while type C tends to ask for contributions to the problems found (TL: 3). Examples of types B and C, respectively, are shown from the following CE042 and CE041 participant problem submission sheets.

Type C only uses a phenomenological representation (CU: 2), while type B uses two implicit phenomenological representations (CU: 3) (researchers perceive that the context of the second sentence is a unity or explanatory sentence from the main question sentence). But the biggest weakness of the two is that the question sentence is outside the concept of chemical equilibrium (CC: 2).

The lower intermediate level in the previous taxonomy (Sawuwu, 2018) signified that participant needed the understanding of chemistry in the text. Figure 3 indicates that participants in this level posed an out of context chemistry question regarding their curiosity or reflection of the text.

Type A

Input:	Process:			Output:
1) Chemical problems are the result of reflection on the content of chemistry articles. 2) The problem is limited to the concept of chemical equilibrium in chemistry articles.	1) Find the concept of chemical equilibrium which is characterized by chemical characters (such as chemical symbols, chemical formulas, and chemical quantities). 2) Explain the chemical concept in chronological order in the selected chemical representation. 3) Provide reflection results.			Presenting the results of reflection and explanation of the chemical problems found.
Initiation	*Metacognitive reading*	*Problem determination*	*Writing the problem*	*Termination*

Type B

Input:	Process:			Output:
A chemistry problem is a question about which the reader cannot find an explanation in the article.	Finding the main phenomenological aspects of the discussion of the topic of chemistry articles.			Inquiry questions whose answers can be found in chemistry articles.
Initiation	*Metacognitive reading*	*Problem determination*	*Writing the problem*	*Termination*

Type C

Input:	Process:			Output:
A chemistry problem is a question about something that cannot be explained in the article according to the reader.	1) Reflect on the chemical problems found in the article. 2) Find the main source of the problem. 3) Directing questions to aspects that are suspected to be the source of the solution.			Inquiry questions about contributing to problem solving without limiting the terms of the problem required
Initiation	*Metacognitive reading*	*Problem determination*	*Writing the problem*	*Termination*

Figure 3. Pattern of the lower intermediate level in the chemistry problem-posing activity

d. Intermediate

The intermediate level has two types of chemistry problem-posing skills as shown in Figure 4. Type A produces a statement of the initial state and its reflection but does not form a question (PS: 2), while type B has become a simple problem (PS: 5). To find out the difference, analyse the PC061 and PC036 participant chemistry problem submission sheets for the following types A and B.

Type A: *"The problem of the threat of coral reefs in aquatic ecosystems is not a trivial problem. Many other problems arise with this problem. Damage to coral reefs is certainly not only caused by the greenhouse effect or other global warming. However, direct human actions such as throwing garbage in the sea can also cause damage to coral reefs and other life in the sea. In addition, the way fishermen find fish using explosives is also a factor in the damage to coral reefs. Garbage that is wasted in the sea, especially plastic, is certainly difficult and takes a long time to be degraded, resulting in landfilling of garbage which even creates new substances that disrupt ecosystem processes in the sea. In this case, it is most likely that* CO_3^{2-} *calcification is more difficult to occur so it is difficult to form coral reefs. Then, explosives that enter the sea leave chemical residues that can inhibit the formation of coral reefs. Therefore, there is a need for socialization and punishment for people who do not want to preserve the ecosystem in the sea."*

Type B: *"High* CO_2 *concentrations can destroy* $CaCO_3$*. This problem is avoided by reducing* CO_2 *production (mainly from human activities). However, marine plants are also capable of producing* O_2*. Then, what marine plants can reduce the concentration of* CO_2 *in the sea so as not to dissolve* $CaCO_3$*?"*

Type A uses two types of representation (phenomenology and process), but they are not complementary (CU: 4), while type B uses symbolic representations that support the phenomenological representation (CU: 5). The reflections made by type A on the problem headings found in the article are well packaged by connecting several appropriate concepts (TOR: 6). While type B makes a considerable error because of the desired final state the problem does not focus on the concept of chemical equilibrium (CC: 2). Based on these two types, the intermediate level still cannot distinguish between chemical problems and non-chemical problems.

Type A

Input:	**Process:**			**Output:**
Chemical problems are the result of reflection on the application of chemical equilibrium problems found in chemistry articles.	**1) Find the problem of chemical equilibrium in chemistry articles.** **2) Comparing the knowledge/experience you have about the problem.** **3) Thinking of solutions to solve problems** **4) Using phenomenological representation dominantly.**			**Make a description and view of the reader about the problem of chemical equilibrium without connecting some of the chemical representations used and propose solutions that do not focus on the chemical aspect.**
Initiation	*Metacognitive reading*	*Problem determination*	*Writing the problem*	*Termination*

Type B

Input:	**Process:**			**Output:**
Chemical problems are questions that contain reflections on chemical equilibrium problems found in the article.	**1) Find the topic of chemistry problems in chemistry articles.** **2) Comparing the knowledge possessed with the topic of the problem.** **3) Focusing on the topic of the problem in one form of chemical representation.** **4) Linking to non-chemical aspects.**			**Inquiry questions about the contribution to problem solving are limited to the terms of the problem but focus on one of the chemical representations.**
Initiation	*Metacognitive reading*	*Problem determination*	*Writing the problem*	*Termination*

Figure 4. Pattern of the intermediate level in the chemistry problem-posing activity.

The intermediate level in the previous taxonomy (Sawuwu, 2018) signified that participants did not understand the structure of a problem. From Figure 4, we find this level can arrange an initial state of the problem using a chemical representation without a complete final state (or well-structured problem).

e. Higher intermediate

The higher intermediate level also has two types of chemistry problem-posing skills with the final state in the form of a question sentence as shown in Figure 5. Generally, the achievement of all parameter levels 3. Submissions of type A and B problems can be seen in the following CE005 and PC022 participant problem submission sheets.

Type A: *"Carbon dioxide (CO_2) is a greenhouse gas that causes the acidification of seawater so that $CaCO_3$ cannot be formed because it shifts the equilibrium that occurs. What other substances besides CO_2 are able to shift the equilibrium? in other words it is more dangerous than CO_2."*

Type B: *"According to the prediction that there will be the year 2100, of course by looking at the facts that exist today, it is very possible if the prediction can come true. Furthermore, what can be done to prevent this? can the concept of chemical equilibrium be used to change the reaction equilibrium to shift to the right, so that the leaching of calcium carbonate can be reduced? On reaction: $CaCO_3(s) + CO_2(aq) + H_2O(l) \rightleftarrows Ca^{2+}(aq) + 2HCO_3^{-}(aq)$. Because the nature of the reaction is also reversible? Can it be?"*

Referring to the chemical information used, type B has a better chemical representation because it uses phenomenological, symbolic, and process representations (CU: 6). In type A, the two process phrases ("acidification process" and "equilibrium shift") become one clause that describes CO_2, so it is assessed using only one type of representation to explain the CO_2 (CU: 3). Types A and B cannot be classified as a problem because there are no discrepancies between the disclosed data.

Structurally, type A questions (PS: 3) are less complex than type B (PS: 4). However, the question word used in type A is a signifier for a higher level of thinking based on the previously created taxonomy (TL: 5). In addition, the chemical concept used by type A (CC: 5) is better than type B, it's just that there are concepts that require special explanation when participants use the clause "that substance is more dangerous than CO_2" (participants have prior knowledge that the level of reactivity of a substance indicates the level of danger of the effect of a substance). Type B erred in applying Le Chatelier's principle in preventing the loss of $CaCO_3$ in the given reaction (AC: 3).

Type A

Input:	**Process:**	**Output:**
Chemical problems are questions that contain chemical equilibrium problems found in chemistry articles and their solutions are speculative-manipulative.	**1) Find the topic of chemistry problems in chemistry articles. 2) Comparing the knowledge possessed with the topic of the problem. 3) Predict solutions to problems that focus on certain chemical representations.**	**Explaining the initial state containing chemical problems and the final state in the form of questions confirming the prediction of a solution or predicting chemical aspects that can be used as a solution.**

Initiation	*Metacognitive reading*	*Problem determination*	*Writing the problem*	*Termination*

Type B

Input:	**Process:**	**Output:**
Chemical problems are questions that contain chemical equilibrium problems found in chemistry articles and the focus of their solutions.	**1) Find the topic of chemical equilibrium problems in chemistry articles. 2) Analysing the specific chemical aspects that are the core of the chemical problem. 3) Comparing non-chemical knowledge possessed with understanding the problem topic. 4) Make general predictions about aspects that can lead to solutions.**	**Describes the initial state containing chemical problems and the final state in the form of problem-solving questions that focus on certain chemical representations.**

Initiation	*Metacognitive reading*	*Problem determination*	*Writing the problem*	*Termination*

Figure 5. Pattern of the higher intermediate level in the chemistry problem-posing activity.

The high intermediate level in the previous taxonomy (Sawuwu, 2018) signified that participants did not use chemical multirepresentations. From Figure 5, we find this level can arrange a problem with initial and final states using certain chemical representation with a directed operator (set solution limits).

f. Excellent

The excellent levels can already produce chemical problems but with some errors in the chemical concepts used. There are two types in this high level as shown in Figure 6. Examples of Types A and B are given in the following CE025 and CE022 participant chemistry problem submission sheets, respectively.

Type A: *"Carbonic acid from the reaction between CO_2 and water will release its proton to become bicarbonate ion reaction: $CO_2(aq) + H_2O(l) \rightleftarrows H_2CO_3(aq)$; $H_2CO_3(aq) + H_2O(l) \rightleftarrows H_3O^+(aq) + HCO_3^-(aq)$. The reaction for the formation of bicarbonate ions from the reversible conversion of bicarbonate ions: $HCO_3^- + H_2O \rightleftarrows H_3O^+ + CO_3^{2-}$. The addition of HCO_3^- will produce a lot of CO_3^{2-} ions which will cause the equilibrium of the formation of $CaCO_3(s)$ to shift towards CO_3^{2-} so that $CaCO_3(s)$ becomes soluble. Are there other reagents that can bind the HCO_3^- ion so that it doesn't react so that not much CO_3^{2-} is formed? How to prevent CO_2 from reacting with H_2O so that acidification does not occur in the sea?"*

Type B: *"CO_2 will protonate H_2CO_3 to HCO_3^-. Whereas CO_3^{2-} is a rock-forming ($CaCO_3$) when reacted with Ca^{2+}. If the CO_2 content increases, the HCO_3^- will also increase, resulting in a shortage of CO_3^{2-} to form $CaCO_3$. So the carbonate equilibrium is unstable. Coral formation and CO_2 solubility are also affected by temperature. Can the excess CO_2 react with other compounds in seawater so that it does not protonate H_2CO_3? And also whether the equilibrium can be re-stabilized by the addition of Ca^{2+} in seawater? Water pollution also affects the carbonate balance?*

Both types use a questioner signifier which is equivalent to thinking level 5 (TL: 5) in taxonomy and uses multiple chemical representations (CU: 6). Type A is classified as a simple problem (PS: 5) although the final state is composed of two questions centred on preventing seawater acidification. Type B is classified as a complex problem (PS: 6) because the final state contains two focus questions, namely protonated CO_2 and the effect of adding Ca^{2+}. However, these two types have quite serious chemical misconceptions (CC: 3). Type A is wrong in understanding the contents of the article that the decay of $CaCO_3$ is due to the increase in carbonate ions (supposedly due to the influence of excess hydronium ions from the acidification process), while Type B is wrong in the concept of protonation of CO_2.

Type A

Input: →	**Process:** →	**Output:**
Chemical problems are questions that contain chemical equilibrium problems found in chemistry articles and the focus of their solutions.	**1) Find the topic of chemical equilibrium problems in chemistry articles.** **2) Analysing the specific chemical aspects that are the core of the chemical problem.** **3) Comparing non-chemical knowledge possessed with understanding the problem topic.** **4) Assess other chemical and/or non-chemical factors that have the potential to limit solution submission.** **5) Make general predictions about aspects that can lead to solutions.**	**Describe the initial state containing chemical problems and the final state in the form of problem solution questions based on several chemical representations.**
Initiation	*Metacognitive reading* — *Problem determination* — *Writing the problem*	*Termination*

Type B

Input: →	**Process:** →	**Output:**
Chemical problems are questions that contain the development of discussions about chemical equilibrium problems found in chemistry articles.	**1) Find the topic of chemical equilibrium problems in chemistry articles.** **2) Analysing the specific chemical aspects that are the core of the chemical problem.** **3) Finding gaps between knowledge/experience, understanding of chemistry articles, and logical thinking on the relationship between information and mastered chemical concepts.** **4) Make a synthesis of thinking from gap analysis and solutions that are thought on certain chemical representations.**	**Describe the initial state containing chemical problems and the final state in the form of problem-solving questions based on several chemical representations.**
Initiation	*Metacognitive reading* — *Problem determination* — *Writing the problem*	*Termination*

Figure 6. Pattern of the excellent level in the chemistry problem-posing activity.

The excellent level in the previous taxonomy (Sawuwu, 2018) signified that participants did not monitor the limitation of problem context. This is difficult to observe because the monitoring aspect is not easily detected in text form. From Figure 6, we find this level can arrange a problem with initial and final states using chemical multirepresentation.

g. Outstanding

The results of the problem analysis for this outstanding level identify one type of chemistry problem-posing skills as shown in Figure 7. An example of this level is the CE013 participant chemistry problem submission.

"With the increasing acidity of seawater, coral reef ecosystems will be disturbed due to the low level of $CaCO_3$ saturation caused by an increase in CO_2 concentration in the

atmosphere. In this case I think whether we can develop a solution such as other than reforestation (to reduce CO_2 levels in the atmosphere) or prohibition to exploit marine life on a large scale or prohibition to dispose of waste (household/industrial), I think that whether we can develop a biota that can produce a compound that is alkaline maybe for example like a biota that can produce ammonia (by symbiosis with other biota) is this possible? Or is there a biota that can produce protein (for example) and then in symbiosis with other biota will produce ammonia, but will the balance of the ocean be disturbed? I was wondering whether to throw away the shells (because I'm originally from the coast and I saw that people have a belief that by taking marine treasures (shellfish, fish, etc.) we must also return the rest to the sea) so whether to throw the shells back? to the sea will help the formation of $CaCO_3$ in the ocean?"

It can be seen that the problem proposed is quite complex (PS: 6) because there are two focuses of the proposed problem, namely creative solutions to the acidification of seawater and confirmation of community myths in the application of the concept of chemical equilibrium. Although the signifier for the question words used is at level 5, the compound structure of the questions discusses the context relationships that are not discussed in the article with the participants' relevant thinking concepts (TL: 6). Participants only use a maximum of two types of chemical representations to explain chemical information (CU: 5). Because the question is a test of thinking results (marked by the clause "can we do it"), the assessment of the accuracy of chemical concepts is only up to the level of participants' ideas. The participant's idea was that acidification affects $CaCO_3$ saturation and this is overcome by linking multidisciplinary solutions (such as policy, acid-base theory, biosynthesis, and sociocultural) that shape socioscientific issues. The context of "ammonia" used by the participants is an example to explain the use of the acid-base theory. Although it has the potential to add new problems, the main idea assessed is the application of acid-base theory in the preparation of these problems.

Input: Chemical problems are questions that arise from the results of critical reasoning about the application of chemical equilibrium problems that are limited by other chemical and non-chemical concepts.	**Process:** 1) Find the topic of chemical equilibrium problems in chemistry articles. 2) Analyse problems on several chemical representations to find the source of the problem. 3) Comparing the knowledge/experience of readers to criticize the source of the problem. 4) Provide alternative solutions based on chemical problem constraints. 5) Assess the weakness of the solution and find further problems			**Output:** Chronologically describes the initial state which contains the discrepancy between the article information, knowledge of chemical and non-chemical equilibrium, and the reader's experience of chemical problems and the final state in the form of questions regarding confirmation of solutions to problems based on several chemical representations.
Initiation	*Metacognitive reading*	*Problem determination*	*Writing the problem*	*Termination*

Figure 7. Pattern of the outstanding level in the chemistry problem-posing activity

The excellent level in the previous taxonomy (Sawuwu, 2018) signified that participant posed a problem significantly in metacognitive level. This requires more detailed explanation of the metacognitive level context. From Figure 7, we find the difference between the excellent and outstanding level. The outstanding level can arrange a problem with initial and final states using chemical multirepresentation and combining the relevant concepts related to the context.

3.2. Participants based on the chemistry problem-posing skills

The categorisation of chemistry problem-posing skills into seven levels is based on differences in input-process-output patterns in the chemistry problem-posing skills stages. Table 4 gives the information of participants' achievement in chemistry problem-posing skill. Based on the seven levels, there are four types of participants in the chemistry problem-posing.

Table 4. Participants' Achievement in Chemical Problem-posing Skill.

The Sum of All Scores	Category	Total	Type	Accumulation
22 ≤ total ≤ 24	Outstanding	09,2%	Metacognitive balance	09,2%
19 ≤ total ≤ 21	Excellent	15,8%	Metacognitive imbalance	39,5%
16 ≤ total ≤ 18	Higher intermediate	23,7%		
13 ≤ total ≤ 15	Intermediate	22,4%	Evaluation errors	22,4%
10 ≤ total ≤ 12	Lower intermediate	23,7%	Planning errors	28,9%
07 ≤ total ≤ 09	Fair	03,9%		
04 ≤ total ≤ 06	Poor	01,3%		

1) Participants with planning errors in chemistry problem-posing skills

Poor (Figure 1), fair (Figure 2), and lower intermediate (Figure 3) levels were owned by participants with the main problem on all parameter scores less than 3. These participants (28,9%) misunderstood the problem terms and chemical concept limits required in the test, which is used to formulate the purpose of submitting a chemistry problem. Failure to formulate this goal indicates a weak participant in the planning strategy which is the first point of determination in chemistry problem-posing skills (Schraw, et al., 2012; Veenman, 2012; Whitebread & Cardenas, 2012). The handling of this type of participant is through increasing the participants' declarative knowledge and procedural knowledge because both are precursors of planning strategies that form the basis for participants to construct reading plans and design what and how to propose problems to be done (Sperling, et al., 2004; Eldar, et al., 2012; Favieri, 2013).

2) Participants with evaluation errors in chemistry problem-posing skills

The intermediate level (Figure 4) is owned by participants with problems with CC scores less than 3 and CU and PS scores less than 4. These participants (22,4%) have not been able to distinguish between chemical questions and problems in sentence structure and chemical understanding. This shows that participants have problems in the components of metacognitive knowledge on task and strategy variables (Whitebread & Cardenas, 2012; Eldar, et al., 2012; Pintrich, 2002; Goh, 2008). These two variables interfere with the participants' metacognitive knowledge (Flavel, 1979) especially on conditional knowledge (Pintrich, 2002) which will affect the evaluation strategy (the fourth point of determination of the chemistry problem-posing skills).

3) Participants with metacognitive imbalance in chemistry problem-posing skills

The higher intermediate (Figure 5) and excellent (Figure 6) levels have reached 50% of the scores for each parameter, but there is no consistency between the parameters (the difference between the highest and lowest scores is more than one) which indicates an imbalance in the metacognitive components of the participants (39,5%). The imbalance of metacognitive components contributes to the quality of chemical problems (Veenman, 2012; Yilmaz-Tuzun & Topcu, 2010). The low TL indicates that participants are weak in metacognitive knowledge, which means that there is an error in their mindset (Krathwohl, 2002), performance (Pintrich, 2002), and understanding at the micro and macro levels of a material (Zohar & Dori, 2012). The low PS and CU indicate that participants lack in metacognitive strategies which means a lack of awareness and regulation of their cognitive strategies (Motague, 1997). The low CC indicates that participants have problems in metacognitive judgments, which means that there is no metacognitive knowledge control in metacognitive strategic execution (Ford & Yore, 2012).

4) Participants with metacognitive balance in chemistry problem-posing skills

The very high/outstanding level (Figure 7) shows that participants (9,2%) have been able to balance all metacognitive components in compiling chemistry problems which are indicated by parameter scores in the range of 5-6. Because metacognition is a process (Biggs, 1988), it can be said that participants with a high level of chemistry problem-posing skills also have good processing skills.

From this current study, a modification of signifiers of the taxonomy is proposed as shown in Table 5. This modification will help one to use the taxonomy and analyse the level of metacognition in chemistry problem-posing. These simpler signifiers will accelerate one in assessing the chemistry problem rather than use the four parameters of the taxonomy, even though it is not detailed in revealing the chemical understanding and concept accuracy. Based on the four types of participants in the chemistry problem-posing, the suggestions are also proposed to improve the skill for each level.

Table 5. Signified Update of The Chemical Problem-posing Skill.

Category	Signified (Previous Study)	Modification of The Signifier (Current Study)	Improvement
Outstanding	The chemical problem is significantly in metacognitive level	arrange a problem with initial and final states using chemical multirepresentation and combining the relevant concepts related to the context	Expand other form of ill-structured chemistry problems
Excellent	The chemical problem is lack of monitoring	arrange a problem with initial and final states using chemical multirepresentation	Train the awareness and regulation to use the chemistry multirepresentation
Higher intermediate	The chemical problem is lack of the representations	arrange a problem with initial and final states using certain chemical representation with a directed operator (set solution limits)	
Intermediate	A problem and a question are indiscriminate	arrange an initial state of the problem using a chemical representation without a complete final state (or well-structured problem)	Train the conditional knowledge to evaluate the process
Lower intermediate	The in-context chemical understanding is required	posed an out-context chemistry question regarding their curiosity or reflection of the text	Train the declarative and procedural knowledge to make a systematic plan to read and arrange the chemistry problem
Fair	The understanding about the problem components is required	a paraphrase of information	
Poor	The task understanding is required	a repetition of information	

Thus, the chemistry problem-posing skill is primarily formed by the ability to plan the process of getting the problem, to evaluate the feasibility of the chemistry problem, and to manage the chemistry multirepresentation composing the problem. By improving the specific ability, students will be able to reach the higher level in metacognition: planning the process through introducing composition of initial and final state of chemistry problems, evaluating the problem through applying conditional and strategic knowledge, and improving chemistry understanding in using multiple chemical representation from phenomenological, symbolic, and microscopic level.

Conclusion

Chemistry problem-posing patterns found in this current study show the flow of the formulation of each problem. The input aspect for the formulation determines the process and the output result. The higher the level, the more complex and multiperspective determinations used for arranging a chemistry problem. The poor, fair, and low intermediate levels have planning problems and are unable to pose a simple chemical problem. The intermediate level had difficulty evaluating the chemistry problem, so that the problem posed were only an incomplete final state or a well-structured problem. The higher intermediate and excellent level had optional problem in strategic, knowledge, or judgement metacognitively, but they can produce a better chemistry problem with an initial state, final state, and operator. The outstanding level can produce a complex ill-structured chemistry problem that indicates a balance in strategy, knowledge, and metacognitive judgment.

Acknowledgements

Thank you to Indonesian Endowment Fund for Education (LPDP) for funding and supporting this research.

References

Ben-Eliyahu, A., & Bernacki, M. L. (2015). Addressing complexities in self-regulated learning: A focus on contextual factors, contingencies, and dynamic relations. *Metacognition Learning*, 10, 1-13. https://doi.org/10.1007/s11409-015-9134-6

Biggs, J. (1988). The role of metacognition in enhancing learning. *Australian Journal of Education*, 32(2), 127-138. https://doi.org/10.1177/000494418803200201

Binbarasan-Tüysüzoglu, B., & Greene, J. (2015). An investigation of the role of contingent metacognitive behavior in self-regulated learning. *Metacognition Learning*, 10, 77-98. https://doi.org/10.1007/s11409-014-9126-y

Blonder, R., Mamlok-Naaman, R., & Hofstein, A. (2008). Analyzing inquiry questions of high-school students in a gas chromatography open-ended laboratory experiment. *Chemistry Education Research and Practice*, 9, 250-258. https://doi.org/10.1039/B812414K

Bruck, A. D., & Towns, M. H. (2009). Analysis of classroom response system questions via four lenses in a general chemistry course. *Chemistry Education Research and Practice*, 10, 291-295. https://doi.org/10.1039/B920834H

Charters, E. (2003). The use of think aloud method in qualitative research: An introduction to think aloud method. *Brock Education Journal*, 12(2), 68-82. Retrieved from https://brock.scholarsportal.info/journals/brocked/home/article/download/38/38

Chopra, I., O'Connor, J., Pancho, R., Chrzanowski, M., & Sandi-Urena, S. (2017). Reform in a general chemistry laboratory: How do students experience change in the instructional approach? *Chemistry Education Research and Practice*, 18, 113-126. https://doi.org/10.1039/c6rp00082g

Demirdogen, B., & Cakmakci, G. (2014). Investigating students' interest in chemistry through self-generated questions. *Chemistry Education Research and Practice*, 15, 192-206. https://doi.org/10.1039/C4RP00037D

Dunlosky, J., & Metcalfe, J. (2009). *Metacognition*. Los Angeles, LA: Sage.

Eldar, O., Eylon, B., & Ronen, M. (2012). A metacognitive teaching strategy for preservice teachers: Collaborative diagnosis of conceptual understanding in science. In A. Zohar dan Y. J. Dori (Eds.). *Metacognitive in science education: Trends in current research* (pp. 225-250). Dordrecht: Springer. https://doi.org/10.1007/978-94-007-2132-6_10

Favieri, A. G. (2013). General metacognitive strategies inventory (GMSI) and the metacognitive integrals strategies inventory (MISI). *Electronic Journal of Research in Educational Psychology*, 11(3), 831-850. http://dx.doi.org/10.14204/ejrep.31.13067

Flavell, J. H. (1979). Metacognition and cognitive monitoring: A new area of cognitive–developmental inquiry. *American Psychologist*, 34(10), 906-911. https://doi.org/10.1037/0003-066X.34.10.906

Ford, C. L., & Yore, L. D. (2012). Toward convergence of critical thinking, metacognition, and reflection: Illustrations from natural and social sciences, teacher education, and classroom practice. In A. Zohar dan Y. J. Dori. (Eds.), *Metacognitive in science education: Trends in current research*, (pp. 251-271). Dordretch: Springer. https://doi.org/10.1007/978-94-007-2132-6_11

Ghasempour, Z., Bakar M. N., & Jahanshahloo, G. B. (2013). Innnovation in teaching and learning through problem-posing tasks and metacognitive strategies. *International Journal of Pedagogical Innovations*, 1(1), 53-62. Retrieved from https://journal.journals.uob.edu.bh//Article/ArticleFile/158

Gilbert, J. K., & Treagust, D. F. (2009a). Introduction: Macro, submicro, and symbolic representations and the relationship between them: Key models in chemical education. In J. K. Gilbert & D. F. Treagust (Eds.), *Multiple representations in chemical education* (pp. 1-8). Dordrecht: Springer. https://doi.org/10.1007/978-1-4020-8872-8_1

Gillette, G., & Sanger, M. J. (2014). Analyzing the distribution of questions in the gas law chapter of secondary and introductory college chemistry textbooks from the United States. *Chemistry Education Research and Practice,* 15, 787-799. https://doi.org/10.1039/c4rp00115j

Goh, C. (2008). Metacognitive instruction for second language listening development: Theory, practice and research implications. *RELC Journal,* 39(2), 188-213. https://doi.org/10.1177/0033688208092184

Grotzer, T. & Mittlefehldt, S. (2012). The role of metacognition in students' understanding and transfer of explanatory structures in science. In A. Zohar dan Y. J. Dori (Eds.), *Metacognitive in science education: Trends in current research* (pp. 79-99). Dordretch: Springer. https://doi.org/10.1007/978-94-007-2132-6_5

Herscovitz, O., Kaberman, Z., Saar, L., & Dori, Y. J. (2012). The relationship between metacognition and the ability to pose questions in chemical education. In A. Zohar & Y. J. Dori. (Eds.), *Metacognitive in science education: Trends in current research* (pp. 165-195). Dordretch: Springer. https://doi.org/10.1007/978-94-007-2132-6_8

Kaberman, Z & Dori, Y. J. (2009a). Metacognition in chemical education: Question posing in the case-based computerized learning environment. *Instructional Science*, 37(5): 403-436. https://doi.org/10.1007/s11251-008-9054-9

Kaberman, Z & Dori, Y. J. (2009b). Question posing, inquiry, and modeling skills of chemistry students in the case-based computerized laboratory environment. *International Journal of Science and Mathematics Education*, 7(3), 597-625. https://doi.org/10.1007/s10763-007-9118-3

Karamustafaoglu, S., Sevim, S., Karamustafaoglu, O., & Cepni, S. (2003). Analysis of Turkish high-school chemistry-examination questions according to Bloom's taxonomy. *Chemistry Education Research and Practice*, 4(1), 25-30. https://doi.org/10.1039/B2RP90034C

Khezrlou, S. (2012). The relationship between cognitive and metacognitive strategies, age, and level of education. *The Reading Matrix*, 12(1), 50-61. Retrieved from http://www.readingmatrix.com/articles/april_2012/khezrlou.pdf

Korpershoek, H.; Kuyper, H; van Der Werf, G. (2015). The relation between students' math and reading ability and their mathematics, physics, and chemistry examination grades in secondary education. *International Journal of Science and Mathematics Education, 13*(5), 1013-1037. https://doi.org/10.1007/s10763-014-9534-0

Krathwohl, D. R. (2002). A revision of Bloom's taxonomy: An overview. *Theory into Practice*, 41(4), 212-218. https://doi.org/10.1207/s15430421tip4104_2

Leopold, C., & Leutner, D. (2015). Improving students' science text comprehension through metacognitve self-regulation when applying learning strategies. *Metacognition Learning*, 10(3), 313-346. https://doi.org/10.1007/s11409-014-9130-2

Liu, Y. & Taber, K. S. (2016). Analysing symbolic expressions in secondary school chemistry: Their functions and implications for pedagogy. *Chemistry Education Research and Practice*, 17, 439-451. https://doi.org/10.1039/c6rp00013d

Montague, M. (1997). Cognitive strategy instruction in mathematics for students with learning disabilities. *Journal of Learning Disabilities*, 30(2), 164-177. doi: 10.1177/002221949703000204

Norris, S. P., & Phillips, L. M. (2012). Reading Science: How a naive view of reading hiders so much else. In A. Zohar & Y. J. Dori. (Eds.), *Metacognitive in science education: Trends in current research* (pp. 37-56). Dordrecht: Springer. https://doi.org/10.1007/978-94-007-2132-6_3

Overton, T., Potter, N., & Leng, C. (2013). A study of approaches to solving open-ended problems in chemistry. *Chemistry Education Research and Practice*, 14, 468-475. https://doi.org/10.1039/c3rp00028a

Pappa, E. T., & Tsaparlis, G. (2011). Evaluation of questions in general chemistry textbook according to the form of the questions and the question-answer relationship (QAR): The case of intra- and intermolecular chemical bonding. *Chemistry Education Research and Practice*, 12, 262-270. https://doi.org/10.1039/c1rp90031e

Pintrich, P. R. (2002). The role of metacogitive knowledge in learning, teaching, and assessing. *Theory into Practice*, 41(4), 219-225. https://doi.org/10.1207/s15430421tip4104_3

Radford, L. (2000). Signs and meaning in students' emergent algebraic thinking: A semiotic analysis. *Educational Studies in Mathematics*, 42, 237-268. https://doi.org/10.1023/A:1017530828058

Sanabria-Rios, D., & Brtez, S. L. (2010). Investigating the relationship between faculty cognitive expectation about learning chemistry and the construction of exam questions. *Chemistry Education Research and Practice*, 11, 212-217. https://doi.org/10.1039/c005470b

Sawuwu, B. Y. (2018). *Taksonomi Keterampilan Pengajuan Masalah Kimia: Eksplorasi Metakognisi Mahasiswa dalam Keterampilan Pengajuan Masalah Kesetimbangan Kimia, Tesis*, Universitas Negeri Yogyakarta. http://eprints.uny.ac.id/id/eprint/59756

Schraw, G., Olafson, L., Weibel, M., & Sewing, D. (2012). Metacognitive knowledge and field-based science learning in an outdoor environmental education program. In A. Zohar dan Y. J. Dori. (Eds.), *Metacognitive in science education: Trends in current research* (pp. 57-77). Dordretch: Springer.

https://doi.org/10.1007/978-94-007-2132-6_4
Sjostrom, J., Eilks, I., & Zuin, V. G. (2016). Towards eco-reflexive science education: A critical reflection about educational implications of green chemistry. *Science & Education*, 25(3-4), 321-341. https://doi.org/10.1007/s11191-016-9818-6
Smith, K. C., Nakhlek, M. B., & Bretz, S. L. (2010). An expanded framework for analyzing general chemistry exams. *Chemistry Education Research and Practice*, 11, 147-153. https://doi.org/10.1039/C005463C
Sperling, R. A, Howard, B. C., Staley, R., & duBois, N. (2004). Metacognition and self-regulated learning constructs. *Educational Research and Evaluation*, 10(2), 117-139. https://doi.org/10.1076/edre.10.2.117.27905
Stickles, P. R. (2011). An analysis of secondary and middle school teachers' mathematical problem-posing. *Investigations in Mathematics Learning*, 3(2), 1-34. https://doi.org/10.1080/24727466.2011.11790301
Tang, K., Delgado, C., & Moje, E. B. (2014). An integrative framework for the analysis of multiple and multimodal representations for meaning-making in science education. *Science Education*, 98, 305-326. https://doi.org/10.1002/sce.21099
Undersander, M. A., Lund, T. J., Langdon, L. S., & Stains, M. (2017). Probing the question order effect while developing a chemistry concept inventory. *Chemistry Education Research and Practice*, 18, 45-54. https://doi.org/10.1039/c5rp00228a
Veenman, M. V. J. (2012). Metacognition in science education: Definitions, constituents, and their intricate relation with cognition. In A. Zohar & Y. J. Dori. (Eds.), *Metacognitive in science education: Trends in current researc*h (pp. 21-36). Dodrecht: Springer. https://doi.org/10.1007/978-94-007-2132-6_2
Whitebread, D., & Cardenas, V. G. (2012). Self-regulated learning and conceptual development in young children: The development of biological understanding. In A. Zohar dan Y. J. Dori (Eds.), *Metacognitive in science education: Trends in current research* (pp. 101-132). Dondretch: Springer. https://doi.org/10.1007/978-94-007-2132-6_6
Wilhelm, J. D. (2001). *Improving comprehension with think-aloud strategies*. New York, NY: Scholastic Professional Books.
Yilmaz-Tuzun, O., & Topcu, M. S. (2010). Investigating the relationship among elementary school students' epistemological beliefs, metacognition, and constructivist science learning environment. *Journal of Science Teacher Education*, 21, 255-273. https://doi.org/10.1007/s10972-009-9163-6
Zohar, A., & Dori, Y. J. (2012). Introduction. In A. Zohar & Y. J. Dori (Eds.), *Metacognitive in science education: Trends in current research* (pp. 1-19). Dordrecht: Springer. https://doi.org/10.1007/978-94-007-2132_1