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Investigating Eleventh Graders' Critical Thinking Skills on Reaction Rate

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Abstract: Critical thinking skills are high-order thinking skills in which students are required to solve complex problems. The topic of reaction rate has conceptual knowledge, cognitive skills, and psychomotor skills that can be used to assess and develop students' critical thinking skills. This study aims to analyze the critical thinking skills of science eleventh graders on reaction rate. This research applies the survey research method. As the research instrument, it uses a critical thinking skills test on the reaction rate consisting of 27 multiple choice questions with a reliability of 0.756 by involving 153 public senior high school students. The authors develop this test. The results show that the average score of respondents' critical thinking skills was 33.66 (low category). At the sub-skill level, the average score of respondents' skills in interpreting was 32.73 (low), analyzing was 29.04 (low), inferencing was 36.77 (low), evaluating was 24.61 (low), and explaining was 33.88 (low). This shows that the learning experiences of the students have not been able to develop their critical thinking skills. Therefore, this research suggests the need for a learning strategy that can be used to improve student's critical thinking skills.

INTRODUCTION

In globalization era, chemistry education has an expanded focus to give greater priority on the development of the 21st Century skills (Romero et al., 2017; Stephenson & McKnight, 2016; Wensing et al., 2018; Worrell et al., 2015). In this sense, the purpose of learning is not only to create individuals who master concepts but also have the skills to find concepts and apply them in everyday life (Badrun et al., 2021; Blaschke & Hase, 2015). The learning process is expected to be able to develop attitudes, knowledge, and skills (MoEC, 2016), in which it aims to prepare Indonesian students in order to be the productive, creative, innovative, and affective individuals who have global competitiveness. One of the 21st Century skills required is critical thinking as part of higher order thinking (Badrun et al., 2021; Hairun & Tonra, 2020; Retnawati et al., 2018). In other words, the learning process should be directed to apply the learning approach that emphasizes on the critical thinking. However, studies on students' critical thinking skills in the field of chemistry are still very limited (Stephenson & McKnight, 2016).

Theoretically, critical thinking skills play an important role in supporting the student success in dealing with complex global problems as a result of the rapid development of technology and information. Thus, critical thinking skills are taught to prepare young generations to face future complex challenges (Rahdar et al., 2018), by emphasizing students' reasoning processes as a basis for solving the complexity of the problems they encountered (Ahuna et al., 2014). The implementation of Critical thinking runs effective when its principles are implied in various disciplines which can facilitate the search for knowledge deeply (Danczak et al., 2020), supported by an emphasis on inquiry tasks (Van Brederode et al., 2020), and collaborative efforts students (Chase et al., 2017). The developing of critical thinking is categorized as a long-term educational goal at all levels (elementary, secondary, and higher) (Danczak et al., 2017). Especially in high school, critical thinking skills are used as the graduate attributes to prepare students to continue on higher education level (Danczak et al., 2020), and also enter the world of work (Prinsley & Baranyai, 2015). In addition, critical thinking skills are needed in students' social environment for adequate decision making (Dwyer & Walsh, 2020). Some research results emphasize the importance of learning chemistry which is able to form relevant student skills, including critical thinking skills. It becomes the main focus of recent discoveries in chemistry education (Astuti et al., 2020; Danczak et al., 2020; Farah & Ayoubi, 2020; Rusmansyah et al., 2019; Sutiani et al., 2021).

According to the 2013 curriculum currently applied in Indonesia, the main learning experiences of students in class consist of observing, asking, trying, associating, and presenting. However, although it is formally stated in the lesson plans that learning process uses an indirect approach (invention, inquiry, project-based, problem-based), classroom practice, in fact, shows that teachers utilize teaching materials by presenting knowledge directly to students (Muntholib et al., 2021). Direct exposure regarding factual, conceptual, procedural, and metacognitive knowledge of students does not provide learning experiences in the aspects of interpreting, analyzing, drawing conclusions, making explanations, evaluating, and self-regulating which are known as important instruments in critical thinking skills (Facione, 2015). Thus, because the implementation of the 2013 curriculum places critical thinking skills as learning outcomes, students' critical thinking skills need to be assessed.

The assessment such as a test is very important in chemistry education in which it can measure students' knowledge and skills, particularly critical thinking skills (Raje & Stitzel, 2020). The assessment is not a complementary instrument in the learning process, but it is an integral part of the learning process as a basis for evaluation in subsequent learning. In this context, critical thinking assessment can be used to assist chemistry education educators and researchers in evaluating the effectiveness of designed learning (Danczak et al., 2020). In addition, assessments by using a means to support critical thinking can train students to answer questions critically so that it can help students to develop critical thinking. In relation to the assessment of students' critical thinking skills, experts have developed several frameworks for critical thinking skills that are often used in research, some of which are the frameworks formulated by Facione et al., (2020) and Ennis,(2015). Of the two frameworks, this study uses the critical thinking skill framework of Facione et al., (2020) because it is simpler and the instrument is easier to develop. Meanwhile, Ennis' critical thinking framework is considered too complex to be used to measure critical thinking which consists of eleven indicators and not all indicators can be achieved by students. According to the framework of Facione et al., (2020), critical thinking skills consist of six sub-skills, namely interpretation, analysis, inference, evaluation, explanation, and self-regulation.

One of the chemical subjects that can be used to practice students' critical thinking is reaction rate. Reaction rate is one of the studies of chemistry subjects (MoEC, 2018) which has conceptual knowledge, cognitive skills, and psychomotor skills that can be used to assess and develop students' critical thinking skills. All phenomena related to the rate of chemical reactions can be used to assess and develop students' skills in interpreting and inferring. The phenomenon of changes in the speed of the sodium metal oxidation reaction by changes in the concentration of HCl can be used to assess students' skills in doing analysis and drawing conclusions. The results of data analysis show that the higher the concentration of HCl, the higher the reaction rate of sodium metal oxidation by HCl solution can be used to assess students' skills in making explanations. Meanwhile, other observations related to the changes in reaction speed between CaCO3 powders by changes in the used HCl concentration can be utilized to assess skills in evaluating the credibility of explanations that have been made previously regarding the effect of concentration of HCl solution on reaction rate.

Research related to critical thinking skills has actually been done quite a lot, especially in the subject of reaction rates (Indahyana & Nasrudin, 2021). However, from a bunch of such research, not all of Facione's critical thinking sub-skills have been analyzed. Research conducted by Indahyana & Nasrudin, (2021), for instance, only analyzed 4 of 5 Facione et al., (2020) critical thinking sub-skills, namely interpretation, inference, analysis, and explanation. To complement previous research, this study aims to investigate the eleventh-grade students' critical thinking skills on the reaction rate by making use of 5 Faciones' critical thinking sub-skills, namely interpretation, inference, explanation, analysis, and evaluation.

METHOD

Development of Critical Thinking Instrument

This study applies a survey research design, namely research that describes various characteristics of a group based on the data collected (Fraenkel et al., 2018). This study is intended to depict students' critical thinking skills on reaction rate. The data collection instrument, namely the critical thinking skills test on reaction rate, was developed by own with the stages of (1) literature review, (2) items development, (3) expert judgment, (4) pilot study, and (5) finalization. The stages of developing this instrument are extracted from the test development research method that has been carried out by previous researchers (Chandrasegaran et al., 2007; Damanhuri et al., 2016; Muntholib, Ibnu, et al., 2020; Wattanakasiwich et al., 2013). The stages of developing critical thinking skills test instrument about the reaction rate can be seen in Figure 1.

Experts judgment in this study is intended to assess the validity of the content and constructs of the developed instrument. This process involves 4 experts, 2 chemistry lecturers and 2 chemistry teachers who have more than 10 years of teaching experience. The results of the analysis show that the average score given by the validators is 93 % for constructs and 90 % for content with very decent criteria.

The item analysis is intended to measure the correlation between the scores of each item and the score of the overall items of an instrument. Acceptable value of correlation coefficient of an item is 0.2 (Ding & Beichner, 2009; Wuttiprom et al., 2009). Item analysis was determined using SPSS 23 for Windows. The validity of the items was analyzed using the Pearson Correlation Test at a confidence level of 95 % (Sig.

0.05). While the reliability test was analyzed using the Spearman Brown Correlation Test at the same confidence level (Sig. 0.05).

The pilot study of the developed test was conducted on 260 twelveth-grade students of SMAN (Public Senior High School) in Mojokerto Regency. The results of the analysis show that among the 30 items made, 27 are valid with a reliability of 0.746 while three are invalid items. Therefore, the final form of critical thinking skills test on reaction rate consists of 27 valid items. The distribution of items of critical thinking skills test on reaction rate into Facione's critical thinking sub-skills is presented in Table 1. This test was then used to survey students' critical thinking skills which was carried out in this study.

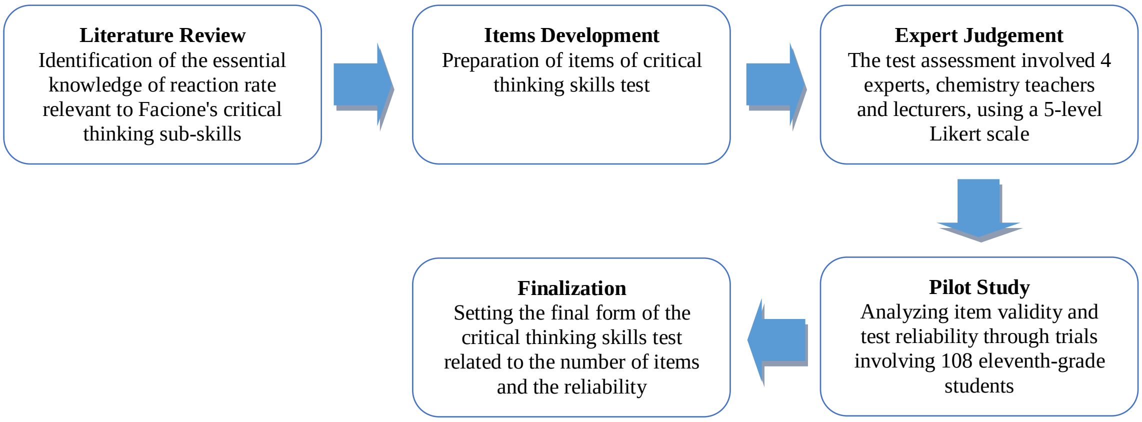


Figure 1. Stages of Critical Thinking Skills Test Development

Table 1. The Distribution of Items of Critical Thinking Skills Test

No	Critical Thinking Sub-Skills	Question Number
1	Interpretation	4, 5, 17, 19
2	Analysis	1, 2, 3, 20, 21, 22, 23
3	Inference	6, 7, 8, 12, 13, 14, 16, 25, 27
4	Evaluation	9, 10, 11, 18, 24
5	Explanation	15, 26

Survey of Students' Critical Thinking Ability

The critical thinking ability survey was conducted on 153 eleventh-grade students in two public senior high school Mojokerto, East Java consisting of 92 female students and 61 male students who had studied the reaction rate material.

The survey sample was selected by simple random sampling from several public high schools in Mojokerto. Data analysis was carried out quantitatively and qualitatively. Analysis of quantitative data to determine the value of the criteria for critical thinking skills from the average score obtained for each sub-critical thinking skill with the following formula.

$$\%\ average\ score = \frac{\sum obtained\ score}{\sum max.score}\ x\ 100\%$$

Qualitative data analysis to determinate level of students’ critical thinking skills was carried out using criteria shown in Table 2 (Heng et al., 2014, 2015; Muntholib, Mauliya, et al., 2020).

Table 2. Level of Critical Thinking Skills

Score (%)	Skills Level
80.00 – 100	Excellent
60.00 – 79.99	Good
40.00 – 59.99	Moderate
20.00 – 39.99	Weak
0.00 – 19.99	Very weak

RESULT AND DISCUSSION

The survey of students' critical thinking skills was carried out using a critical thinking skills test consisting of 27 valid items developed by own-self. These questions are distributed into 5 sub-skills of critical thinking (Facione et al., 2020). The students' achievements of each critical thinking sub-skills are presented in Figure 2.

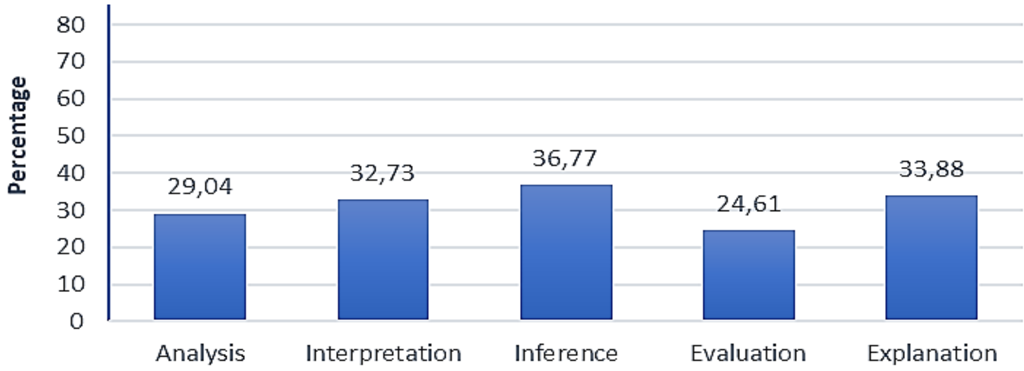


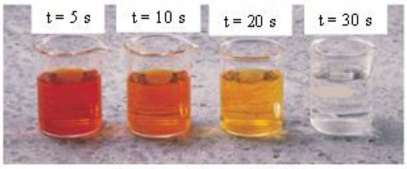
Figure 2. The Students' Critical Thinking Skills for each Sub-Skills

Figure 2 shows that respondents' skill in analysis is 29.04 % (weak), in interpretation is 32.73 % (weak), inference is 36.77 % (weak), in evaluation is 24.61 % (weak), and in explanation is 33.88% (weak). These implies that respondents' critical thinking skills are weak in all sub-skills.

Learning outcomes reflect learning experiences of instruction (Muntholib, 2018). The low of students' critical thinking skills indicate that they do not practice critical thinking in the teaching and learning process. Formally, the Indonesian curriculum of 2013 applies inquiry-based instruction which suggests students perform activities of critical thinking skills. However, in practice, critical thinking skills tend to be dictated to students to be understood, not practiced to develop skills. The instruction tends to be done in one direction from teacher to student. Direct instruction is effective and efficient for teaching content knowledge. This approach achieves more content knowledge by involving students' reading skills (Slocum & Rolf, 2021). The better the reading skills and the ability to listen to the teacher's explanation, the better the students' understanding. Direct instruction learning helps students understand chemical concepts through teacher explanations, but not to train critical thinking skills such as analysis, interpretation, inference, explanation, evaluation, and self-regulation. The direct instruction syntax varies, one of which is: 1) orientation, 2) presentation, and 3) structured, guided, and independent practice (Joyce et al., 2003).

In the orientation stage, the teacher provides an overview related to learning including: learning objectives, the importance of the material to be studied, presenting prior knowledge, presenting some of the experiences experienced by students related to the material, and conveying activities that will be carried out by students in learning. In the presentation stage, the teacher presents the material by doing illustrations, demonstrations or verbal explanations with the help of learning media or not. After the presentation is complete, the teacher provides feedback through a question and answer session with students as evaluation material while ensuring that all students receive the material well. Giving structured, guided and independent assignments is an effort by the teacher to help students strengthen the concepts that have been obtained in the learning process. In giving guided assignments, the teacher also guides students to correct mistakes. If as many as 85 % of students have been able to solve several problems in guided assignments, it can be said that students can follow assignments independently in class or at home (Joyce et al., 2003). Judging from the direct instruction learning stages, it reflects that students only rely on the transfer of knowledge and skills from the teacher.

The following figure shows a mixture of bromine and formic acid solutions at various reaction times.



Source: Chang, 2010

The reaction equation for the mixture of the two solutions is as follows.

$$Br_2(aq) + HCOOH(aq) \rightarrow 2H^+(aq) + 2Br^-(aq) + CO_2(g)$$

Brown Colorless

The evidence for reducing the concentration of reactants in each solution is....

A. Change in solution volume
B. Change in the color intensity of the solution
C. Change in solution temperature
D. The formation of a precipitate
E. Formation of gas

Figure 3. Examples of Inference Question

A total of 5 grams of Aluminum sulfate (alum) as the limiting reactant was reacted with 100 mL of distilled water. The results of the observations are as follows.

Trial	Alumunium sulfate	Late Time
1.	Chunk	70 second
2.	Powder	20 second

Based on the observational data, what are your conclusions? Explain using the concept of reaction rate!

A. The reaction of alum powder with distilled water is slower, the contact area of alum powder with aquadest is smaller, the smaller the chance of particle collision so that the reaction takes place quickly.
B. The reaction of alum powder with distilled water is faster, the contact area of alum powder with HCl is greater, the greater the chance of particle collision so that the reaction takes place quickly.
C. The reaction of lump alum with distilled water is slower, the contact area of lump alum with aquadest is larger, the smaller the chance of particle collision so that the reaction takes place slowly.
D. The reaction of lump alum with distilled water is faster, the contact area of lump alum with aquadest is larger, the greater the chance of particle collision so that the reaction takes place quickly.
E. The reaction rate between the powder and lumps of alum with distilled water could not be observed.

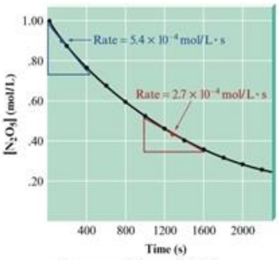
Figure 4. Example of Explanation Question

The inference skills of students are low because at the stage of direct instruction learning orientation, the teacher only presents a fact about their experience related to the material but does not present problems as well as how to solve problems related to facts or phenomena. This causes students to find it difficult to group some of the necessary elements from existing evidence or facts to draw a conclusion or an appropriate assumption regarding the facts or other phenomena presented. It can be seen from one of the inference questions that have been developed that some students are less able to provide evidence of a change in concentration in the solution resulting from a chemical reaction between bromine and formic acid (question in Figure 3). However, students' inference skills are said to be the best when compared to the other four skills because students can guess the right statements based on existing facts. Inference skills can be improved by providing opportunities for students to interact directly with the subject of learning in observing objects or events that occur based on the material that has been achieved during the learning process (Atikoh & Prasetyo, 2018).

Students' skills in providing explanations have a better position after inference skills but are still categorized as low. In one of the questions that measure explanatory skills, students are asked to provide a true statement (argument) regarding an experimental result based on the concepts, evidence and facts that have been obtained (questions in Figure 4). However, the achievement of explanatory abilities is still categorized as low because students are not able to provide reasoning where they do not understand the concept to provide an explanation. The efforts are needed to improve skills of providing explanations, one of which is by increasing the knowledge of students (Basri et al., 2019). Students who have less knowledge will have difficulty in providing explanations. In the contrary, if students have sufficient knowledge, they then can provide good explanations (Utami et al., 2018). However, in direct instruction learning, the teacher fully presents material or important concepts that cause students not to find their own knowledge so that the knowledge possessed by students is less meaningful and only students who listen to the teacher's explanation as a whole have more knowledge. Meaningless knowledge will be recorded in a short period of time, causing students' knowledge of the concepts presented to be less good.

The following is a graph of the concentration of N_2O_5 against reaction time:

$$2N_2O_5(aq) \rightarrow 4NO_2(aq) \rightarrow O_2(g) \text{ (T = 458°C)}.$$



Source: Chang, 2010

Based on the graph above, what is the trend of the instantaneous rate with the concentration of the reactants as the reaction time goes on?

A. The instantaneous rate increases as the concentration of the reactants decreases.
B. The instantaneous rate decreases as the concentration of the reactants decreases
C. Reaction time and reactant concentration do not affect the instantaneous rate.
D. The instantaneous rate increases with increasing reaction time
E. The instantaneous rate decreases with decreasing reaction time

Figure 5. Examples of Interpretation Question

In addition, the presentation of material by the teacher only presents the core concept in the form of conclusions from the phenomenon without presenting experimental data in the form of graphs, tables, or diagrams causing the lack of students' ability to provide a meaning from diagrams, graphs, and tables. This causes students to be unable to draw conclusions from data in the form of diagrams, tables or graphs presented, so that students' interpretation skills are low. In one of the questions that measure interpretation skills, it appears that students are less able to draw conclusions regarding the effect of reactant concentration on the instantaneous rate as reaction time based on a graph of reactant concentration against reaction time with an instantaneous rate of each second (question in Figure 5).

The analysis and evaluation skills are included in the HOTS skills and are very difficult for students to master. In direct instruction learning, teacher explanations with presentations and providing feedback by asking students questions are deemed unable to improve students' skills to conduct analysis and evaluation because students tend to provide answers to questions in accordance with what was conveyed by the teacher without conducting analysis or evaluation first. This shows that students do not involve complex thinking to answer the teacher's questions, while the analysis process requires complex thinking such as looking for relationships between certain information (attributing) to become a unified whole (organizing) or vice versa (differentiating). The analysis process can be done by conducting an investigation so as to get a conclusion. Likewise, with providing an assessment that requires students to have a strong foundation related to evidence, concepts and methods in order to be able to provide precise and convincing arguments. However, in this study students were not able to provide an assessment because the basic concepts possessed by students were not strong enough so that the evaluation skills of students were low. Seen in the analysis problem, students are less able to analyze several factors that affect the reaction rate based on some experimental data (question in Figure 6) and are unable to evaluate by providing a convincing justification regarding the expression of the reaction rate based on the submicroscopic picture of the reaction for the formation of product A from the reactants B (question in Figure 7).

The speed of the reaction between 10 mL $Na_2S_2O_3$ solution and 10 mL HCl solution can be seen from the reduced mass of the solution mixture because ***SO_2 gas is released*** by the following chemical reaction.

$$Na_2S_2O_3(aq) + 2HCl(aq) \rightarrow 2NaCl(aq) + S(s) + SO_2(g) + H_2O(l)$$

The following are the results of the experimental reaction rate observations.

Reaction	$[Na_2S_2O_3]$ (M)	[HCl] (M)	Temperature (°C)	Initial mass of the mixture	Mass of the mixture in 60 seconds
1.	0.1	0.1	27	0.2 gram	0.18 gram
2.	0.1	0.2	27	0.2 gram	0.15 gram
3.	0.2	0.2	27	0.7 gram	0.65 gram
4.	0.2	0.2	40	0.7 gram	0.53 gram

Factors that affect the rate of the reaction is ....

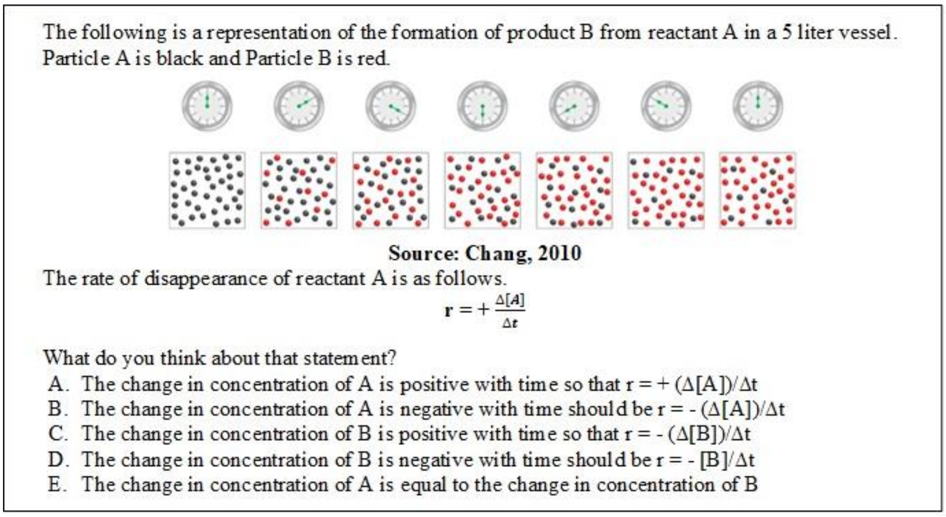
A. The color of the solution and the mass of the solution
B. Surface area and volume of solution
C. Solution concentration and reaction temperature
D. Surface area and reaction temperature
E. Concentration and volume of solution

Figure 6. Example of Analysis Questions

The last stage of direct instruction learning is structured, guided, and independent assignments that also affect students' critical thinking skills. Assignments given to students do not reflect critical thinking so that students are less trained to think critically. The importance of training critical thinking in students in order to prepare students to solve problems which will be faced in present and future life through critical thinking, making appropriate and responsible decisions through several considerations.

Innovative learning is needed to introduce students' critical thinking by overcoming difficulties in working on questions that require reasoning, analysis, and evaluation. Innovative learning can help students be more active in the learning process very well to overcome the low critical thinking skills of students

(Munawaroh et al., 2018). Inquiry learning by involving a problem is one of the learning innovations. Problems raised in learning can be in the form of contextual problems and socioscientific issues that are now a trend in science teaching. Problem-based inquiry learning involving students' scientific literacy has proven to be very effective in guiding students systematically in learning science (Ayyildiz & Tarhan, 2018; Simaremare et al., 2018; Sutiani et al., 2017) and motivating students to learn chemistry actively and improve critical thinking skills (Kahlke & Eva, 2018).



The following is a representation of the formation of product B from reactant A in a 5 liter vessel. Particle A is black and Particle B is red.

Source: Chang, 2010

The rate of disappearance of reactant A is as follows.

$$r = +\frac{\Delta[A]}{\Delta t}$$

What do you think about that statement?

A. The change in concentration of A is positive with time so that r = + (Δ[A])/Δt
B. The change in concentration of A is negative with time should be r = - (Δ[A])/Δt
C. The change in concentration of B is positive with time so that r = - (Δ[B])/Δt
D. The change in concentration of B is negative with time should be r = - [B]/Δt
E. The change in concentration of A is equal to the change in concentration of B

Figure 7. Example of Evaluation Questions

The investigation was carried out by exploring a phenomenon that would trigger students' curiosity (Arsal, 2017; Birren & Kieboom, 2017; Jeffery et al., 2016) so that some research data were obtained. Inference skills are developed when students plan investigations such as determining research variables as the basis for finding evidence and facts to prove the hypotheses that have been made (Sutiani et al., 2021). In the investigation of interpretation skills can develop well (Hohmann & Grillo, 2014; Styers et al., 2018) when students are able to interpret and explain the data from the investigation by formulating categories through depiction, and analogy to the meaning of words, ideas, concepts, numbers, pictures, symbols, charts, graphs, or certain events (Facione, 2015). Students explore knowledge through investigations through laboratory activities and literature studies to answer questions posed by conducting a good analysis (Saputri et al., 2019). The data from the analysis are then discussed together to obtain proper verification of information by providing an assessment (evaluation). Information held by students from various sources is studied more deeply to obtain information that is mutually supportive or contradictory (Pedaste et al., 2015). Explanation skills are reflected when students justify reasoning in the form of convincing arguments from research data to make logical conclusions. The ability to give conclusions is an important aspect in practicing critical thinking skills that are explanation skills.

CONCLUSION

Based on the survey results, the average score of students' critical thinking skills on the reactions rate is 33.66 % (weak). This indicates the need of instruction that provides students with experience to practice critical thinking skills. A learning experience is not only written in the lesson plan, but it is actually practiced by students in the teaching and learning process. The use of critical thinking test instruments in learning can be used as an effort to familiarize students with practicing critical thinking questions. However, this research is limited to a critical thinking survey of reaction rates in two schools in one city. Further research can be carried out with similar research with a wider sample involving samples from several schools in one province so that the research results will be more representative.

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