Analysis of STEM-PBL based e-module needs to improve students' critical-thinking skills

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Abstract. STEM is a learning approach that integrates the teaching of science and mathematics through scientific inquiry, technology and engineering, and mathematical analysis to develop 21st century skills. One of them is critical-thinking skills that are thinking skills involving cognitive, analytical, rational, and logical processes and inviting students to do reflective thinking to problems. The application of STEM which is integrated with problem-based learning and packaged in an e-module will produce creative individuals with critical thinking. The design of the research uses qualitative description. It aims to investigate the need for teaching materials in the form of STEM-PBL based e-Module and critical thinking profiles of students in senior high schools. The subjects of the research were 75 students and 1 chemistry teacher. The data were collected through several techniques such as interviews, questionnaires and critical-thinking essay tests. The results show that students cannot think critically in solving chemical problems and need teaching materials in the form of STEM-PBL-based e-Modules.

1. Introduction
Chemistry is the science of matters and their changes [13]. Most chemistry is an abstract concept, so it is difficult to understand, especially when students should believe something invisible [19]. In learning chemistry, teachers and students are faced with three levels of representations, namely macroscopic, submicroscopic, and symbolic. The macroscopic level explains chemical phenomena that can be observed directly including in everyday experience [21]. Submicroscopic level is a chemical phenomenon that is difficult to see directly, so it requires theories to explain it. Students encounter this level when studying the atomic theory. There are particle terms such as electrons, atoms, and molecules that are generally related to the molecular level [6]. The symbolic level is a varied chemical representation such as models, images, algebra, computational forms, formulas, and reaction equations [7] [21]. In this case, students need critical-thinking skills to connect the three levels of representations to achieve the objectives of chemistry learning.

Over time, technology and education have developed. The development of the world of education raises several problems. One of them is the learning process does not produce students who are thinkers. Teachers only pursue the completeness of the material without thinking about how students learn and connect their skills, one of which is critical-thinking skills [11]. Critical thinking is the ability to reason and think reflectively that is directed to decide the things that are convincing to do [8]. These skills will benefit both in solving chemical problems and preparing the students to compete in the international market. Someone with good critical-thinking skills has a set of cognitive skills and
dispositions [9]. In the learning process, critical thinking is high-order thinking in using language, making conclusions, calculating results, making decisions, and solving problems.

Based on the results of the PISA (Programme for International Student Assessment) in 2015, Indonesia experienced an increase in overall subjects both in science, literacy and mathematics compared to the results of PISA in 2012, although not significant [16]. In the 2012 PISA results, the average scores for science, literacy, and mathematics were 382, 396, and 375, respectively. Meanwhile, the 2015 PISA results were 403, 397, and 386, respectively [15]. The average score is still below the international average score and overall, Indonesia is still at the bottom level, ranking 62th out of 69 countries in 2015. OECD (Organization for Economic Co-operation and Development) states that in the future, Indonesia will have difficulty preparing workers who have 21st century skills. Therefore, there needs to be improvements in learning especially chemistry to improve the skills, especially critical thinking.

STEM is a learning approach with a focus on educating students in four disciplines, namely science (S), technology (T), engineering (E) and mathematics (M), and then integrating them into real problems, so students can think critically in taking action as practical application [22]. STEM learning can help students solve problems and draw conclusions from previous learning by applying them through science, technology, engineering and mathematics [17]. STEM education can make student learning more relevant and meaningful, thus deepening their understanding [5]. In the world of education, the objectives of STEM are in line with the demands of 21st century education i.e. the students have scientific and technological literacy as shown in the ability to read, write, observe, and develop skills to solve everyday problems related to STEM science [4] [14]. STEM education combines problem solving, analytical, critical-thinking skills, and communication as a pedagogical strategy [18]. With this assumption, teachers can integrate learning models that provide problems into the STEM approach to improve students' critical thinking. The learning model that fits this objective is Problem-Based Learning (PBL). In PBL, students are provided with daily chemistry-related problems and conduct an independent/group investigation to find a solution. PBL consists of five syntaxes, namely problem orientation, organizing students to learn, guiding independent/group investigations, developing work, and analyzing problem solving [2]. In integrating STEM-PBL, the teacher can package it into an e-module that can be accessed via the Internet. The characteristics of e-Modules as the teaching material are self-instructional, self-contained, standing alone, user friendly, and adaptive [20]. This research aims to investigate the needs for teaching materials in the form of STEM-PBL-based e-Modules and critical-thinking profiles of students in senior high schools.

2. Methodology
This research is descriptive-qualitative with the research subjects of 1 chemistry teacher who has 16 years of teaching experience and 75 eleventh-grade students. This research was conducted at a school located in Surakarta City, Central Java, Indonesia. It is a high-category senior high school based on the results of the National Examination of the chemistry subject. Data collection used interviews, questionnaires, and essay tests. Closed questionnaires were given to students to find out the need for alternative teaching materials. The questionnaire consists of seven questions and uses a positive and negative direction test with two choices of "Yes" and "No" answers. The researcher conducted an interview with the chemistry teacher to find out the teaching model and teaching material applied in the classroom. To find out the profiles of students' critical thinking, the researcher conducted a test with essay questions on the acid-base material. The test consists of 4 questions arranged based on five aspects of critical thinking, namely (1) giving a basic explanation, (2) building basic skills, (3) concluding, (4) providing further explanation, and (5) strategy [8].
3. Result and Discussion

3.1. Chemistry Learning in Class
The learning process in the classroom is an important factor for students to achieve learning objectives. The application of approaches, models and teaching materials that are suited to students’ needs will help develop critical-thinking skills. Critical thinking in learning chemistry requires students to understand not only concepts and principles, but also its application in everyday life. The overlap or interconnections between chemistry materials when learning through critical thinking will help students understand more specifically about the chemical properties, functions, formulas or equations.

3.1.1. Giving Questionnaire Sheet to Students
This activity aims to find out teaching materials that have been used to study chemistry, whether the students have difficulties in learning and they need teaching materials that can improve critical-thinking skills. Closed questionnaires were used because they are easy to fill out and do not require a long time. The questionnaires were given to the eleventh-grade students in each school. The results of the questionnaires given to students are explained in Table 1. 93.3% of students have difficulty learning chemistry because they do not have other teaching materials besides textbooks. Only 26.7% of all students search for other teaching materials and not all chemistry materials can be applied in practical activities in the laboratory. All students need alternative teaching materials, namely electronic mosses based on STEM-PBL.

| No  | Question                                                                 | “Yes” Answer Percentage (%) |
|-----|--------------------------------------------------------------------------|------------------------------|
| 1.  | Do students use chemistry textbooks as learning resources?                | 73.3                         |
| 2.  | Are they searching for other teaching materials?                         | 26.7                         |
| 3.  | Does the teacher use a module to study chemistry?                        | 0                            |
| 4.  | Do practicum activities in the laboratory help to understand the chemistry material? | 20                           |
| 5.  | Do students experience difficulties in learning chemistry?               | 93.3                         |
| 6.  | Do they need alternative teaching materials?                             | 100                          |
| 7.  | Do they need STEM-PBL-based e-Module to improve critical-thinking skills?| 100                          |

Learning difficulties prevent students from developing critical-thinking skills. Students who experience difficulties are indicated by a failure in achieving learning objectives. Learning failures occur when: (a) within a certain time limit, the student has not reached the minimum mastery of material set by the teacher (leaver group), (b) the students can not achieve the achievements as they should (under achiever), (c) they cannot realize the tasks of development (immature), and (d) they cannot master the material needed as a requirement the continue to the next level of knowledge (slow learners) [3]. Thus, students need other teaching materials that are interesting and have the potential to develop critical-thinking skills.

3.1.2. Interview
The interview with the teacher was conducted to support the data obtained from students. The result of the interview provides information in line with the result of the questionnaire, in which the teacher still uses textbooks and student worksheets in the learning process. The teacher gives students the opportunity to search for other teaching materials. In the classroom, the teacher has not implemented STEM learning and the learning process still uses discussion and jigsaw methods. According to the teacher, critical-thinking skills are important in learning chemistry. A student who has not been taught this skill will find it difficult to argue and draw conclusions. An argument and conclusion drawn with critical-thinking skills also give students the opportunity to defend it [10]. Unfortunately, the teacher
states that students have difficulty in critical thinking. Students can only mention without giving reasons underlying their answers. They only accept the concept of the material without reasoning and developing their arguments.

3.2. Students’ Critical-Thinking Profile

Through the essay test instrument, the researcher investigated the profiles of students' critical thinking on the Acid-Base material. The test has four questions arranged according to aspects and indicators of critical thinking by Ennis. The results of the investigation on each aspect and indicator of critical thinking were then interpreted qualitatively.

3.2.1. Aspect of Providing Basic Explanations, Indicators: Focusing Questions.

The purpose of this indicator is to focus students on the problem or event by formulating questions. In measuring this indicator, the students were given an event as follows:

"Motorbikes can be started without being connected to an electric current. This is because batteries function as chemical energy converter into electricity. In the battery cell, there is a solution of sulfuric acid which functions as the electrolyte. The sulfuric acid solution will ionize to produce hydrogen ions and sulfuric ions. The ions cannot react to form sulfuric acid solution. What problems do you get? Identify by considering possible correct answers.."

The correct Answer: "Is Sulfuric Acid a strong electrolyte?"; "What particle has a role in delivering the electric current so that the motor turns on?"

Based on the students' answers, only 20% of them can make questions correctly. The rest, 80% of students, make questions that are less focused, simple, and without explanation. The most questions formulated are:

"How does sulfate anion move from battery water to the engine?"

The question above is not related to the event in the problem. Focus is important in arranging questions related to the events presented, thus making students' minds more focused which ultimately knows the main points, issues and problems of the event (Ennis, 2001).

3.2.2. Aspect of Building Basic Skills, Indicators: Considering Source Conformity

Considering whether the source is trustworthy or not is the purpose of this indicator. In this indicator, the students were given the following events:

"Aspirin is an analgesic with the main content of salicylic acetyl acid. It is a weak acid with pKa = 3.5 and Ka = 3.27 x 10^-4. When consumed, it will be absorbed by the blood through cells lining the stomach and small intestine. Because the pH of the gastric fluid is around 1 and the pH in the small intestine is around 6, in what part is aspirin more absorbed into the bloodstream, stomach or small intestine? Give your reasons clearly."

Based on the data, only 32% of students gave the right answer and reason according to the suitability of the information source. They can give reasons that aspirin is more absorbed in the small intestine. Acidic aspirin (Ka = 3.27 x 10^-4) will be more easily absorbed by a solution with greater pH (pH = 6), so it will be more neutral. The students can answer the questions based on credibility considerations, namely using evidence and facts and linking events given with existing theories [1].

3.2.3. Aspect of Providing Further Explanation, Indicators: Clarifying Explanations

Based on the data, 20% of students can provide further explanations related to pH calculation as shown in Figure 1. The rest, 80% of students, do not give any answers.
In Figure 1, the students can provide further explanations about the pH of rainwater by drawing a pH route based on the color change of each indicator.

### 3.2.4. Concluding Aspect, Indicators: Inducing

The purpose of this indicator is to determine the ability of students to infer the events presented in the first problem. In line with the first problem, 20% of students who can formulate the questions correctly can also infer events related to Sulfuric Acid (H$_2$SO$_4$) solution, which is a strong electrolyte.

### 3.2.5. Strategy Aspect, Indicators: Determining an Action

Selecting criteria to consider and determine solutions is the objective of this indicator. Students are given illustrations of submicroscopic representations of Hydrogen Fluoride (HF) solution when dissolved in water. This representation explains the particle level at which matter molecules are described as the arrangement of atoms, molecules, and ions (Johnstone, 1982). In other cases, students are asked to illustrate submicroscopic representations of Hydrochloric Acid (HCl) solutions in water. Based on the data, 86.7% of them answer incorrectly as in Figure 2. The remaining 13.33% can determine the action by reviewing the completion step of the Hydrofluoric Fluoride (HF) solution as in

![Figure 2. Students’ Incorrect Answers](image)

![Figure 3. Students’ correct Answers](image)

In Figure 2, students assume that hydrochloric acid solution when dissolved in water does not break down into its ions. Thus, through their actions, students describe it as an intact Chloride Acid molecule. Meanwhile, in Figure 3, students can make the decision that Hydrochloric Acid solution is a strong acid which is proven by describing the submicroscopic representation of HCl solution decomposed into H$_3$O$^+$ (aq) and Cl$^-$ (aq) ions.

### 3.3. STEM-PBL Based e-Modules

STEM implementation can be supported by various learning models, one of which is problem based learning. This model refers to five points such as: student-centered learning, learning in small or independent groups, the teacher as a facilitator, the presence of problems can stimulate students to learn and develop critical thinking skills. Figure 4 shows a matrix of STEM-PBL-based e-Modules.
Electronic modules provide students the opportunity to use information and communication technology through computers or smartphones. So, learning is more interesting and flexible. The use of e-modules has several objectives such as: students can learn independently, teachers are not dominant in learning, students can measure their own level of mastery of the material, and accommodate various levels or speed of student learning.

Figure 4. STEM-PBL Based e-Module Matrix
4. Conclusion
The results indicate that only 10-30% of students can think critically in every aspect. Thus, it can be concluded that most students have not been able to think critically. They need other alternative teaching materials in the form of e-Module based on STEM-PBL to improve critical-thinking skills.

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