Dimension of Chemical Literacy and its Influence in Chemistry Learning

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Abstract. Chemical literacy is an ability that is important for students to have in the current educational era. This study aims to measure the ability of chemical literacy of high school students by using questionnaires and questions through investigation. This research was a qualitative descriptive study with samples engaging 100 students from Surakarta and Boyolali High Schools. This study investigated the achievement of the ability of chemical literacy of high school students in class XI and XII for the material of electrolyte and non-electrolyte solutions. The measured chemical literacy abilities included: a) nominal literacy (recognizing the concept of chemistry); b) functional literacy (defining key concepts); c) conceptual literacy (using chemical understanding to explain the phenomena of everyday life); and d) multi-dimensional literacy (using the understanding of chemistry to analyze information provided in short articles or other reading sources). The test instruments used were questionnaires, choice questions, and open-ended questions supplemented with interviews to obtain the data on the concept of students' chemical literacy. The results of the study found that students were able to explain the concept of chemistry at the macroscopic level, but in the submicroscopic level the students’ ability was still low. This showed that students' chemical literacy skills at the conceptual level and multi-dimensional literacy were still less. The findings of this study can help design learning strategies and teacher readiness in supporting students to develop students' chemical literacy skills.

Keywords: Chemical literacy; Macroscopic; Submicroscopic.

1. Introduction

The 21st century learning is a new demand in achieving a solid educational concept someday. Just as technological developments are increasingly advanced and developing, education will also concomitantly lead to such advancement and development. Chemistry learning is one example of a small part in the 21st century learning system that will develop. Chemistry is an abstract concept that in understanding of it needs a variety of perspectives because chemistry will address not only the senses that can be seen and felt but also things more than those whereby chemistry also discusses how to explain a phenomenon from the submicroscopic world that will further explain what can be felt or macroscopic, and how to make symbols to explain the phenomenon [1]–[5]. Chemistry tries to explain macroscopic phenomena in terms of the microscopic structure of matter [6].

Humans who have knowledge and the understanding of the relationship of science, technology and society and who are able to apply them in daily life according to Bond are called humans who have scientific literacy [7]. One part of scientific literacy is chemical literacy referring to an individual's
understanding of particle matter, reaction, law, theory and chemical applications in everyday life. Individuals who have good chemical literacy skills are able to apply the aspects of chemical literacy skills including the ability to explain events in daily life within the concept of chemistry; ability to solve problems in everyday life by using chemical understanding; and the ability to understand and apply chemical applications in everyday life [6], [8]–[11]. Chemical literacy is categorized into four domains, namely scientific and chemical content knowledge, chemistry in context, higher-order learning skills, and affective aspects. From here, it is expected that high school graduates can find out the key ideas of each domain. The measurement of chemical literacy uses a scale of scientific literacy which is comprised of nominal literacy, functional literacy, conceptual literacy, and multi-dimensional literacy [6], [12]–[14].

Nominal literacy shows that students are able to recognize words related to science but cannot explain them meaningfully. At this level, students are only able to remember the concepts and terms but have not shown meaningful understanding yet. They have misconceptions about them. Functional literacy is the ability to use scientific concepts to read and write about science and technology, but misconceptions are still found in these concepts. Students explain the concepts with memorization, but when asked to explain in their own words students have not been able to do it. The ability of multi-dimensional literacy requires students’ understanding of the concepts vis-a-vis science and technology from the philosophical and historical perspectives, and their ability to connect their understanding with society and everyday life [13], [14].

Chemical literacy is needed by teachers and students in understanding of the broad and abstract concept of chemistry. The teacher must of course make students think and have the ability to combine and predict a chemical concept in their daily lives. The students will be helped in terms of how they will study chemistry by seeing the chemistry of what they feel and experience every day. The need for this understanding needs to be an understanding of teachers and students in dealing with the concept of chemical literacy. As is well known, Indonesian students’ literacy skills are rated at number 57 from 67 countries.

In this study, an analysis of the actual state of literacy that we work on is more specific to students’ chemical literacy abilities and their relationship in understanding the chemical concept [15].

The rest of this paper is organized as follow: Section 2 describes the proposed research method. Section 3 presents the obtained results and following by discussion. Finally Section 4 concludes this work.

2. Proposed Method

The purpose of this study was to measure the chemical literacy levels of high school students in Surakarta and Boyolali, Indonesia. This article hopes to be able to map the ability of high school students to understand chemical literacy and its relationship with how to understand the concept of chemistry. In this case, the chemical literacy dimensions used are nominal, functional, conceptual and multi-dimensional as stated by the dimensions of chemical literacy. Specifically, the chemical literacy is focused on how students have chemical literacy in studying chemistry.

2.1. The Participant

The participants consisted of 100 students of class XI and XII at high schools from Surakarta and Boyolali. Surakarta high school students numbered 60 students from 12 schools, and Boyolali high school students totaled 40 students from 6 schools. The chosen samples were determined based on random sampling method. The material of chemistry that we used in order to know the participants’ chemical literacy is the electrolyte and non-electrolyte solution whereby we considered this material to be studied by participants. Inasmuch as the participants were derived from the students of class XI and XII, we could definitely assume that students had learned and understood the concept of the material in prior.
2.2. The Data Collection

In order to understand the dimensions of chemical literacy ability, it was required the right tools in describing the concept of students’ chemical literacy. Therefore, a device that adopted Swartz’s steps was used [8]. The tools used were questionnaires supplemented with interviews to probe and obtain the data about the concept of students’ chemical literacy. The questionnaires used to measure the ability of chemical literacy in this study used electrolyte and non-electrolyte solution. The data were collected from three different questionnaires i.e.:

The first questionnaire was used to measure the students’ nominal literacy abilities. This questionnaire contained a number of statements about chemical concepts. In this questionnaire, Likert scale statements (1-3) were used. The statements in the questionnaire were used to find out students’ recognition of the chemical concepts.

The second questionnaire consisted of seven statements addressing the chemical concepts in daily life. This questionnaire was used to measure the conceptual literacy skills oriented to students’ understanding of chemistry to explain everyday problems. Students must be able to use their conceptual understanding of chemical concepts and processes at this level of literacy[16]. This questionnaire presented a phenomenon in everyday life with each statement followed by an example. This questionnaire could also be called choice questions because in the questionnaire there were three alternative choices that could be chosen correctly. Students could work on the problem by choosing "Correct statement"; "Incorrect statement" or "I don't know".

The third questionnaire was used to measure the level of functional literacy and multi-dimensional literacy of the students. This questionnaire was also referred to as open-ended questions, which asked students to define some of the concepts of functional literacy, and more specifically whereby students made connections with various disciplines between science, technology and society for multi-dimensional literacy. Students used their understanding of chemistry to analyze the information provided in the given short article. Functional literacy measurements used an article about isotonic drinks, and then students should find the key concepts why isotonic drinks could be accepted by the body. Meanwhile, the measurement of multi-dimensional literacy used an article about the use of alum in water purification. After reading the article, a number of questions were given to measure students’ reading comprehension, ability to relate their chemical knowledge to questions, and reasoning.

3. Result and Discussion

Students’ chemical literacy skills can be measured using four levels of chemical literacy according to Shwartz [8], namely nominal literacy, functional literacy, conceptual literacy, and multi-dimensional literacy. The instrument used was in the form of questionnaires and test questions that had been divided according to four levels of chemical literacy.

3.1 Nominal Literacy

In nominal literacy, students understand the concept, but in their understanding misconceptions are still found. Nominal literacy level was measured using a questionnaire consisting of seven statements about chemical concepts as described in Table 1. Students were asked to assess the level of recognition of each concept available in the questionnaire. Assessment was done using a Likert scale (1-3) starting from "Don't know the concept", "Know the concept", to "Understand the meaning of concept". Assessment was adjusted to the actual circumstances of each student. The statements used in the questionnaire are as follows [17].
Table 1. Statements in the questionnaire

| Statement                                                                 | Don’t know the concept | Know the concept | Understand the meaning of concept |
|---------------------------------------------------------------------------|------------------------|------------------|-----------------------------------|
| 1. Definition of solution                                                 |                        |                  |                                   |
| 2. Solution phase                                                         |                        |                  |                                   |
| 3. The concept of solution based on electrical conductivity               |                        |                  |                                   |
| 4. Electrical conductivity testing                                        |                        |                  |                                   |
| 5. Submicroscopic level of electrolyte and non-electrolyte solutions      |                        |                  |                                   |
| 6. Non polar covalent compounds                                           |                        |                  |                                   |
| 7. Ionization of electrolyte and non-electrolyte solutions                |                        |                  |                                   |

Based on the questionnaires that had been filled in by students, the obtained data indicated that most students did not understand the concept of submicroscopic levels of electrolyte and non-electrolyte solutions. The results of this acquisition were supported by students’ answers while working on the following essay question. “What is the image of an electrolyte solution molecule in the accumulator if the sulfuric acid electrolyte solution is replaced with a vinegar acid solution?” Students’ answers can be seen in Figure 1.

![Image](image-url)

Figure 1. Students’ answers at submicroscopic level

The answers given by students were very diverse. A small number of students could answer the question and explain it correctly, but most students still experienced misconceptions. In the accumulator, there is an H$_2$SO$_4$ electrolyte solution which is a strong acid. H$_2$SO$_4$ solution is a type of strong electrolyte solution, which is a completely ionized solution that is capable of producing free-moving ions. Therefore, the solution of H$_2$SO$_4$ will decompose completely into H$^+$ ions and SO$_4^{2-}$ ions. This will be different when the H$_2$SO$_4$ electrolyte solution is replaced with a solution of vinegar or CH$_3$COOH solution. CH$_3$COOH solution is included in the type of weak electrolyte solution because this solution is a weak acid. Solutions derived from weak acids cannot be fully ionized so that the solution H$^+$ ions and CH$_3$COO$^-$ ions are formed, and there is still a CH$_3$COOH molecule itself[18][19]. From Figure 1.a it could be seen that there were still found students who experienced misconceptions whereby CH$_3$COOH solution was considered to be fully ionized to form H$^+$ ions and CH$_3$COO$^-$ ions. In the meantime, in Figure 1.b students could answer correctly that CH$_3$COOH solution was a weak acid so that in the solution there was still CH$_3$COOH molecule itself. In fact, students who answered with the answer as seen in Figure 1.a were more numerous if compared to those who answered like picture 1.b.
The responses showed that students had a poor conception of the submicroscopic level at electrolyte and non-electrolyte solution. Students could not explain how the electrolyte solution could be ionized into its constituent ions. This can be caused by the lack of learning that includes submicroscopic levels in chemistry. The learning served by the teacher is only achieved at the macroscopic and symbolic level. In addition, it is also because the books and learning tools used by the teacher do not include submicroscopic levels. Students tend to only memorize without knowing how to conceptualize the real material so that students experience difficulty in representing submicroscopic levels.

Understanding the submicroscopic level is very important in studying chemistry because chemistry is related to not only what we see but also what happens to molecules. As we know, when electrolyte solutions such as sulfuric acid can produce electricity in accumulator. In this case, what we see when electricity is generated by accumulator is about the macroscopic level. Meanwhile, why ions formed from \( \text{H}_2\text{SO}_4 \) are ionized and interact with \( \text{PbO}_2 \) and \( \text{Pb} \) as cathodes and anodes of the flow of electrons moving and making electricity cannot be explained simply by looking at the phenomenon in the macroscopic level.

Understanding the macroscopic level makes students able to have imagination and abstractive thinking in understanding of chemical phenomena. Abstractive chemistry also becomes easy to understand when all phenomena in the macroscopic level can be explained through the submicroscopic level. The need for this leads the teacher to be able to present learning that can accommodate this. The need for students’ new understanding of how to grasp the world of submicroscopic level is actually needed for how students can describe the phenomenon that occurs especially predicting the relationship between macroscopic level and submicroscopic level.

3.2 Functional Literacy

Functional literacy is a higher level than nominal literacy. At this level, students can describe concepts correctly, but still have limited understanding. The question used in measuring the ability of functional literacy level was set in the form of open-ended questions. Students were provided with an article about isotonic drinks. The article consisted of one paragraph, and under the article was provided a picture of the illustration pertinent to receiving isotonic drinks [8]. Students were asked to explain why isotonic drinks could be accepted by the body. The question mentioned is as follows: "Based on the description above, why are isotonic drinks acceptable to the human body?".

Most students still experienced errors in answering the question. The reasons mostly given by students can be seen in Figure 2. a below.

![Image](image_url)

(a) The most students’ answers, (b) Isotonic drink concept

The answer above is not right because what is asked is the reason why isotonic drinks can be accepted by the body. In the words of isotonic drinks, there is a keyword referring to "isotonic" which consists of the word "iso" which means "same" and "tonic" which means "pressure". Hence, isotonic drinks are the drinks that have the same osmotic pressure as the pressure of fluids in the body. This is what causes isotonic drinks to be accepted by the body.
The explanation of why isotonic drinks can be received by the body can also be analyzed from Figure 2.b contained in the question sheet. Figure 2.b shows the submicroscopic level of isotonic drinks entering the body. From these images, it can be illustrated that isotonic drinks are appropriate or have the same osmotic pressure as the fluid in the body so that isotonic drinks can enter the body. Such isotonic drinks help balance the composition of fluids in the body that have been lost through sweat or urine. Isotonic drinks enter the body to replace electrolytes, minerals and sugars that have been lost so that a balanced composition is formed in the body [18], [20].

Based on the results of students' answers, it could be seen that the ability of students at the functional literacy level was still low. Students knew the concept but had not clearly understood what was meant by the problem, so that in answering the question students still experienced difficulties and led to errors in providing the answers.

3.3 Conceptual Literacy
Conceptual literacy includes students' understanding of the main conceptual schemes of a material, and then linking the scheme to a general understanding of chemistry. In addition, conceptual literacy also includes procedural understanding and the understanding of the investigation process or inclusion. Measurement of conceptual literacy was done by using the choice question "Correct statement", "Incorrect statement" or "I don't know". The problem consisted of seven statements about chemical phenomena in everyday life[8]. Presents in Table 2

| Statement                                                                 | Correct Statement | Incorrect Statement | I don’t know |
|---------------------------------------------------------------------------|-------------------|---------------------|--------------|
| 1 In a sugar solution, water is a solvent, whereas sugar is a solute.     |                   |                     |              |
| 2 Salt can conduct electricity in both liquid and solid forms.            |                   |                     |              |
| 3 Lemon is an alternative electrolyte solution because it contains citric acid compounds. Therefore, lemon can produce electricity. |                   |                     |              |
| 4 HCl solution used as a porcelain cleaning mixture has a lower electrical conductivity than syrup solution. |                   |                     |              |
| 5 In the vinegar acid solution, a small number of ions will form so that they cannot turn on the lamp on the electrolyte test equipment and only cause gas bubbles. |                   |                     |              |
| 6 Isotonic drinks can replace fluids, electrolytes, and sugar lost in the body due to heavy activities. |                   |                     |              |
| 7 In the sulfuric acid solution contained in the accumulator, the H+ ions and SO₄²⁻ ions will decompose completely so that they can conduct electricity well. |                   |                     |              |

As shown in Table 2, the ability of students at the level of conceptual literacy could be known from the results of the work on the question. Students who had high conceptual literacy skills could do the questions well, while students who had low conceptual literacy skills would have difficulty in understanding the problem. The questions used were a matter of applying electrolyte and non-electrolyte solutions in daily life[21][22].

From the results of the students' work, it was found that the majority of students did not know the concept of the difference in the solution of electrical conductivity in real life. HCl solution is a strong acid solution that can be ionized completely, while a syrup solution is made of glucose which is a non-electrolyte solution. Strong electrolyte solution will conduct electricity well so that it has a higher electrical conductivity than syrup solution. Accordingly, the statement “HCl solution used as a porcelain cleaning mixture has a lower electrical conductivity than syrup solution” is incorrect statement[17], [19].
3.4 Multi-dimensional Literacy

The multi-dimensional literacy level is the highest level in the ability of chemical literacy. At this level, the ability of students is drawn on to not only understand the concept of chemistry but also combine scientific inquiry procedures. Here, students also develop an understanding of the material concepts with the application of science and technology in their daily lives. More specifically, students make connections with various disciplines, between science, technology and society. With the ability of chemical literacy at the multi-dimensional literacy level, students are expected to be able to solve the problems that arise in social life [8].

Multi-dimensional literacy level measurement was done by giving a sort of open-ended question. Students were given an article about the use of alum in the water purification process, and then at the bottom a picture of the water purification process was provided. Students could understand the concepts contained in the article and images as well as connect the concepts with everyday life as outlined in the questions. The question asked was divided into two cases which were uttered as "From the article above, please explain the principle of alum's work in the process of water purification!" and "What do you think if in the process of purifying the water a large amount of alum is used? Explain the reason!" [6].

Students’ answers indicated that they had understood the working principle of alum in the water purification process, but they still experienced misconceptions on the second case of the question. The second question was intended to find out the students’ opinions appertaining to the condition if alum was used in large quantities; it was not harmful to human health. In fact, many students answered that the more alum was used, the more effective the water purification process would be so that the water became clearer. Even though this statement is still wrong, alum is after all an additional material whose use must be in accordance with the rules of use. Although alum is found on the market and is sold freely, it does not mean one hundred percent safe if it is used as an ingredient in the body, such as to preserve food or purify water. The use of excessive alum can cause poisoning, and if used in the long term, it will have worse consequences, especially for health [19], [22], [23].

4. Conclusion

Based on the results obtained in this study, students’ chemical literacy skills are considered still low. The ability of students at the nominal level and functional literacy is good enough at the macroscopic level. Students are able to understand the concept of chemistry at the macroscopic level, but if it has been linked to the submicroscopic level, students still experience difficulties and misconceptions. This can be caused by the lack of learning that includes submicroscopic levels in chemistry. The learning served by the teacher is only achieved at the macroscopic and symbolic level. In addition, the books and learning tools used by the teacher do not also include submicroscopic levels. Students tend to only memorize without knowing how to conceptualize the real material so that students experience difficulty in representing submicroscopic levels.

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