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# Students' chemical literacy: A study in chemical bonding

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# Students' chemical literacy: A study in chemical bonding

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**Abstract**. Scientific literacy is the ability to understand science, communicate science, and apply science skills to solve a problem. Scientific literacy skills, especially chemical literacy are things that must be possessed by students in the 21st century. This study aims to analysis students' chemical literacy abilities in chemical bonding material. The research use quantitative approach by survey method. A total of 199 first year students from four Public High Schools were randomly selected in the school category, they have very good accreditation in the Special Region of Yogyakarta, Indonesia. Data were collected by test techniques with Chemical Bonding Literacy Test (CBLT). The instrument consist of chemical literacy ability open-ended questions with three aspects namely the context, chemical knowledge content, and Higher-Order Learning Skills (HOLS) in the form of 21 questions about chemical bond material. The analysis of students' chemical literacy ability is done by categorizing the scores obtained from the test into the ideal ranking category. The results of this study indicate that students' chemical literacy ability are still very low as evidenced by the results of the analysis students entered into the bad category. This study suggest that students need to be extra in develop their chemical literacy skills, especially in the aspects of connecting and analyzing scientific information.

## 1. Introduction

The 21st century was marked by changes in the rapid development of science and technology in people's lives. Therefore education are faced with increasing challenges by delivering human resources who have the ability and skills to face the challenges of life in this century. Education today is directed to prepare students to be successful life in the 21st century by encouraging learners to have a base of knowledge and a deep understanding to become life-long learners [1]. Because education is a crucial aspect of advance or retreat of a life [2].

Students need to be equipped with skills to deal with the challenges of the 21st century in order to be able to compete in the era of globalization. The rapid development of the globalization era has made education required to be able to shape scientific literacy that has the ability to think scientifically to solve individual problems and community issues so that it can play a role as a qualified human resource as shown by the scientific literacy. Previous research [3] stated that chemistry education provide a great potential and strategic role in preparing qualified human resources to face the era of industrialization and globalization. Therefore, it is important to incorporate 21st century skills in science education.

One of the skills needed in the 21st century is scientific literacy [4]. Scientific literacy is defined from the Program for International Student Assessment (PISA) as the ablility to apply scientific knowledge, identify issues, describe scientific phenomena, draw conclusions based on evidence, and the willingness to reflect on and engage with scientific ideas and subjects [5]. Scientific literacy embodies scientific ideas, concepts and concepts in practice in and in many disciplines [6]. Chemistry, which is one of the branches of science, also has educational goals that are in line with science, that is, people who are chemically illiterate can later form a society of literary science.

Indonesia is being reviewed from the Indonesian Education quality and access mapping results in 2013-2014. Indonesia is 40 from 40 countries on the mapping of the learning curve-person [7]. In a report by OECD for scientific literacy in 2015, Indonesia was 62 from 70 countries with a score of 403 [8]. The results of this survey of scientific literacy abilities led Indonesia to be categorized as a country with low scientific literacy skills. Obtaining a lower score implies that the Indonesian students have limited knowledge of science and chemistry learning achievement also reflects the low level anyway. The low level of this chemistry literacy can be influenced by several factors including the learning process, teacher competence, curriculum used, and learning resources. Lack of students' scientific literacy skills is a reason that undertook the Indonesian Government to perform the curriculum's revision of the 2006 to 2013. Gilbert, Bulte, and Pilot [9] categorizes problems in the chemistry curriculum in five different groups; i.e. overload, separate facts, lack of transfer, lack of relevance, and a lack of emphasis in learning.

Chemical literacy describe [6] includes four components: first is the chemical content of knowledge that explain how a chemically-literate student should understand a common chemical idea, as well as using knowledge to explain a phenomenon and understand the characteristics (key ideas) of chemistry in explaining the process, the reaction in chemistry. The second component is chemistry in context stating that a chemically-literate student should be able to use chemical knowledge to explain chemistry in explain the chemistry in everyday life in providing social arguments regarding problems and innovations in chemistry. The third component is about Higher-Order Learning Skills (HOLS) that referring to the questions and investigate any relevant information pertaining to the chemical/chemistry. The last component is an affective aspects which explain that a chemically-literate person must have a chemical perspective and can apply it and must demonstrate an interest in chemical problems in everday life.

Chemistry is a subject that most students consider difficult. For students the concept of chemistry is difficult to learn and for them chemistry is just a field that is less popular in the future to learn [10]. In addition, they assume many calculations in chemistry and eventually they have learning difficulties [11]. For example in chemical bonding material, Students can not understand the concept of the types of chemical bonds so that difficulties in distinguishing between these chemical bonds. Even though chemical bonding material is an important sub-material for high school students to study. Previous research [12] also confirmed that the chemical bonding material is more abstract, it is usually more difficult to understand, the linkage with the understanding of the previous material relatively much like the structure of atoms, the properties of the element periodicity makes students less motivated to learn.

Learning chemistry includes the discussion of the material in submakroskpik, submicroscopic and symbolic, sometimes referred to the three tiers of representative chemical [13] Previous research results [10] stated that the methods used in learning are lacking in connecting chemical concepts with real life, so that they are not sufficient to improve students' chemical literacy. Chemical literacy is very important, this is related to how students are able to appreciate nature by utilizing the science and technology they have mastered [14]. Students who have chemical literacy must understand the basic concepts of science/chemistry [6]. Therefore, chemical literacy of students is very important to analyze in order to improve student performance in the process of learning chemistry.

## 2. Methods

### *2.1 Research design and samples*

This research is a quantitative approach by survey method. Participants in this study came from four Public High Schools in the Special Region of Yogyakarta, Indonesia. This study used a convienence sampling. A total of 199 10th grade high school students with an average age of 16 years consisting of 99 female and 100 male students were participants in this study.

*2.2 Techniques and data collection instruments*

Chemistry literacy data are collected by test techniques. The instrument used in this study is called a Chemical Bonding Literacy Test (CBLT) consist of chemical literacy ability open-ended questions. The CBLT was developed based on the definition of chemical literacy [6] and [15] in measuring chemical literacy. Chemical bonding materials in the chemical curriculum in Indonesia include Lewis structure, ionic bonds, covalent bonds, coordination covalent bonds, compound polarity, metal bonds, intermolecular forces and physical properties of compounds. The question sheet consists of 21 description questions which are used as post-learning tests which are broken down into 4 topics which are adjusted to the sub-material of chemical bonds namely ionic bonds, covalent bonds, compound polarity and metal bonds. Each sub-subject of chemical bonding includes 3 aspects of chemical literacy ability, namely the chemical aspects in the context, aspects of chemical knowledge content, aspects of Higher-Order Learning Skills (HOLS). HOLS consists of identifying the information needed, linking scientific information, analyzing scientific information, and the ability to argue. The following is a summary of the grids of chemical literacy instruments can be seen in Table 1.

**Table 1**. Chemical literacy instruments grids.

| Contexts | Chemistry Sciences Content | HOLS |
|---|---|---|
| Topic 1. Ion bonds: chemistry in kitchen salt (NaCl) | | |
| Contexts | Chemistry Sciences Content | HOLS |
| The dangers of excessive NaCl kitchen salt consumption. | Understand and disclose the process of formation of an ionic bond. | Connecting scientific information. |
| | Understand and disclose ion bonds using their structures and processes. | Analyzing scientific information. |
| | Understand and disclose the properties of ion compounds using their structures and processes. | Analyzing scientific information. |
| | Providing chemical/chemistry knowledge to explain phenomena in the health field. | Identifying required information. |
| | | Argue. |
| Topic 2. Covalent bonds: chemistry in bleach (NaClO) and ammonia (NH3) | | |
| Contexts | Chemistry Sciences Content | HOLS |
| The danger of mixing two cleaning materials to clean obstinate stains. | Understand and disclose covalent bonding formation processes. | Connecting scientific information. |
| | Understand and disclose the process of forming mixed chemical bonds (ionic bonds and covalent bonds). | Connecting scientific information. |
| | Understand and disclose covalent bonds using the structure and process. | Analyzing scientific information. |
| | Understand and disclose mixed chemical bonds (ion bonds and covalent bonds) using the structure and process. | Analyzing scientific information. |
| | Understand and disclose PEB and PEI using the structure and process. | Identifying required information. |
| | Understand and disclose chemical bonds using structures and processes. | Analyzing scientific information. |
| | Providing chemical/chemistry knowledge to explain phenomena in the health field. | Argue. |
| Topic 3. Compound polarity: chemical bonding in the used cooking oil | | |
| Contexts | Chemistry Sciences Content | HOLS |
| Used cooking oil is B3 waste that has the potential | Providing chemical/chemistry knowledge to explain phenomena in the enviroment field. | Identifying required information. |
| | Understand and explain the polence of compounds that are | Analyzing scientific |

| | | |
|---|---|---|
| to damage the environment. | reviewed from its properties. | information. |
| | Understand and explain polar and non-polar compounds using their structures and processes. | Analyzing scientific information. |
| | Providing chemical/chemistry knowledge to explain phenomena in the enviroment field. | Argue. |
| Topic 4. Metal bonds: chemical bonding in aluminum foil | | |
| Contexts | Chemistry Sciences Content | HOLS |
| The danger of consuming foods that are heated with aluminum foil. | Understand and explain the bonding of metals using the structures and processes. | Connecting scientific information. |
| | Understand and explain the properties of the metal bonding using the structure and process. | Analyzing scientific information. |
| | Providing chemical/chemistry knowledge to explain phenomena in the health field. | Identifying required information. |
| | | Argue |
| | | Identifying required information. |

Analysis instrument chemistry literacy tests conducted by theoretical and empirical validity and reliability. Theoretical validity is done by asking for improvement and expert advice in terms of material, construction, and language (item readability) in the form of an assessment of the feasibility of the items of the instrument to two experts from the Department of Chemical Education. The assessment by experts is qualitative. After getting feedback from the validator such as suggestions and improvements for the instruments used in this study, revisions were made and then validation continues with empirical validity.

Empirical validity was conducted by administrate the CBLT to other students who are not used as research samples. Students used to test chemical literacy test instruments empirically have certain criteria. The criteria in this case include having an average age of 16 years and have studied the subject of chemical bonding. A total of 134 students obtained for testing chemical literacy test instruments that have been developed. Based on the results of empirical validity analysis there is 1 item from 22 items the CBLT that is not in accordance with the Partial Credit Model (PCM). This means that as many as 21 items of CBLT are in accordance with the PCM model. These 21 items were used as instruments to measure students' chemical literacy abilities. In addition, the results of the analysis showed an estimate of Cronbach's Alpha reliability of 0.78 which was included in the good category. It means that the CBLT can be used to collect the data.

### *2.3 Data analysis technique*

The data analysis technique used to determine the profile of chemical literacy abilities is based on the scores of chemical literacy tests on each topic in a quantitative descriptive analysis that has steps namely: (1) recap the score of each topic from the instrument data used, which is the test chemical literacy ability; (2) make the ideal score range and assessment category; (3) categorizing the scores obtained according to the ideal rating category.

Chemical literacy profile categories are divided into 5 categories, namely very good, good, sufficient, less good, bad. Determination of ideal assessment categories refers to the suggestion by [16] with the highest ideal score of 42 and the lowest ideal score of 21. Ideal rating categories as afollows.

Table 2. Ideal rating categories.

| Category | Score Range |
|---|---|
| Very Good | $36,75 < X$ |
| Good | $35 < X \leq 36,75$ |
| Sufficient | $29,75 < X \leq 35$ |
| Less Good | $26,25 < X \leq 29,75$ |
| Bad | $X \leq 26,25$ |

## 3. Results and discussion

The results of chemical analysis of chemical literacy ability on chemical bonding materials as follows.

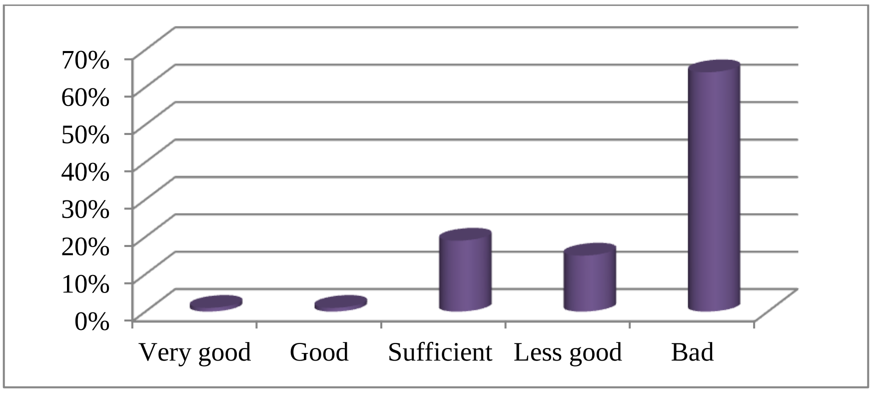


**Figure 1.** Profile of Chemical Literacy Ability on Chemical Bonding Materials

Figure 1. shows that the largest number results of students' chemical literacy abilities in chemical bonding material are included in the bad category. This portray that the school learning has not yet fully trained the students' chemical literacy ability. Students are not familiar with chemistry learning associated with the context of the life around them, so the concepts of chemical bonding materials that can not be mastered by the student and the student having difficulty in resolving the problem in these contexts. Students' misconceptions about these concepts are based on the fact that they are only able to understand lecture at the macroscopic level and the difficulty follows a shift between the macroscopic and sub-macroscopic levels [17]. Most students also have a lot of mistakes in identifying what is require from the problem. If students are not accustomed to complete the test, the students' scientific literacy skills will tend to lower [18].

Most students cannot connect and analyze scientific information from reading texts from the question of literacy. Especially in covalent and metal bonding materials, many students are trapped so that they cannot answer what is asked of the problem. This is because the methods used in learning are not suitable to make students accustomed to working on literacy-based questions. And also educators must have good abilities in teaching students so students have chemical literacy ability. Science literacy provides aspirations for curriculum development, teaching materials and assessment practices, so that if the material and learning science are facilitated with the aforementioned competencies, scientific literacy of students will develop [19] [20].

### *3.1 Topic 1. Ion bonds: chemistry in kitchen salt (NaCl)*

Results of chemical analysis of literacy skills in ionic bonding material on the topic of chemical bonds in kitchen salt (NaCl) which is included in the health field is presented in Figure 2.

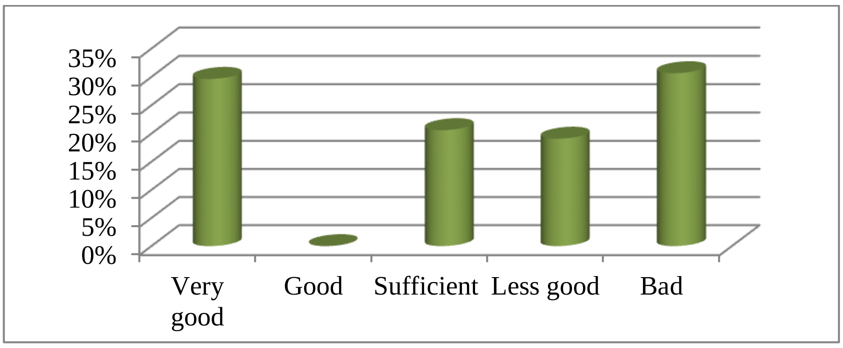


**Figure 2.** Profile of Chemical Literacy Ability on Topic 1.

Topic 1 contains the context of the dangers of excessive consumption of NaCl salt. The results of the analysis show that the categories of students' chemical literacy abilities with the highest percentage are in the very good and bad categories. On this topic students can connect scientific information in determining the type of bonding in a salt compound. Students can identify information on chemical knowledge in explaining the hazardous context of excessive consumption of NaCl salt and can provide arguments to the phenomenon in the health sector. This portray that students are able to connect the context in the problem with the chemical concepts they have. A learning that uses students 'daily experiences combined with chemical content will produce chemical concepts that will be left behind in students' thinking, so students can use that knowledge to solve problems and students have new knowledge and experience [21]. The relevance of science in everyday events can improve students' ability to transfer knowledge and make students understand why they must learn science so learning becomes meaningful [9].

However some students are weak in explaining the process of forming ion bonds in NaCl compounds. The students' mistakes in describing the ionic bonds in reaction and Lewis structure are, among other things, are incorrectly determining the number of electrons released and received by NaCl constituent elements, writing symbols in ion bond formation reactions, and depicting the number of electron electrons. Students have a problem in understanding the ionic bonds that occur between the atoms of Na and Cl, in terms of the images of students showing that chemical bonds are formed between the atoms of Na and Cl through the division of electrons instead of transferring electrons from one atom to another [22].

*3.2 Topic 2. Covalent bonds: chemistry in bleach (NaClO) and ammonia (NH3)*

Topic 2 contains about the dangers of mixing the two cleaning agents to clean obstinate stains. The results of the analysis of the ability of chemical literacy on the material of covalent bonds on topic 2 are presented in Figure 3.

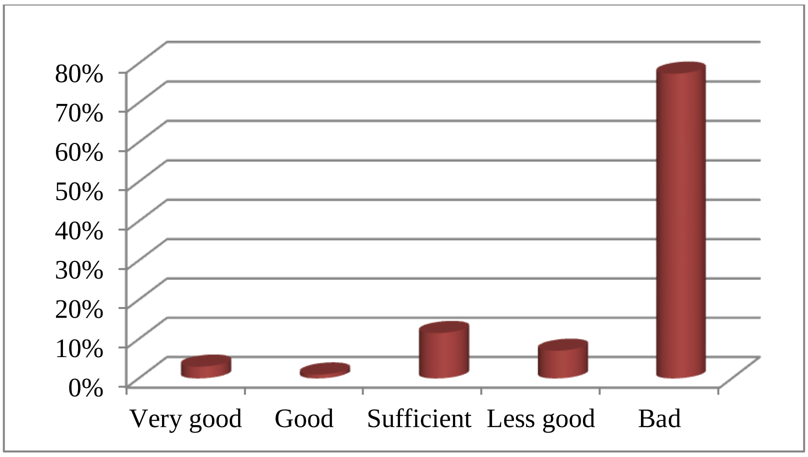


**Figure 3.** Profile of Chemical Literacy Ability on Topic 2.

The analysis illustrated that the covalent bonding material is the most difficult topics when compared to three other chemical bonding material, as it contains issues that most of the students are not able to finish. More than half of all students fall into the bad category because many students cannot connect and analyze scientific information in understanding and disclosing the process of forming mixed chemical bonds (ionic bonds and covalent bonds) using their structures and processes. The results of a similar study [23] reveals there are many misconceptions concept of covalent bonds even though the students were able to recite the definition of the covalent bond.

This has an effect in determining the number of Free Electron Pairs (PEB) and Bond Electrons (PEI) in compounds containing ionic and covalent bonds. In the terms of the students' answers, most of them are misconceptions about the mixed chemical bonds. Misconceptions occur in determining and disclosing the process of the formation of NaClO compounds. Students are correct when answered that there is an ionic bond between $Na^+$ and $ClO^-$, but many students have misconceptions about the bonds that occur in $ClO^-$. The answers of some students indicate that the bond that occurs in $ClO^-$ is a coordination covalent bond, whereas the answer should be a single covalent bond. Chemical bonds are basically taught by emphasizing the dichotomy of molecules and compounds that will be classified as ionic or covalent [24]. If the students have a different concept of the concept of science is what is meant by misconceptions [25]. Overall on this topic students are not quite mastered the concept of chemical bond materials. It is characterized by students can not use the concepts he already has in solving the existing problems in the question, contrary to the statement [26] about the possibility that occurs when the student has mastered a concept that has the characteristics of students can use these concepts to problem solving and mastery of concepts make it easier for students to learn other concepts .

*3.3 Topic 3. Compound polarity: chemical bonding in the used cooking oil*

Figure 4 shows the results of chemical analysis of literacy skills in the context of the B3 waste cooking oil that could potentially damage the environment.

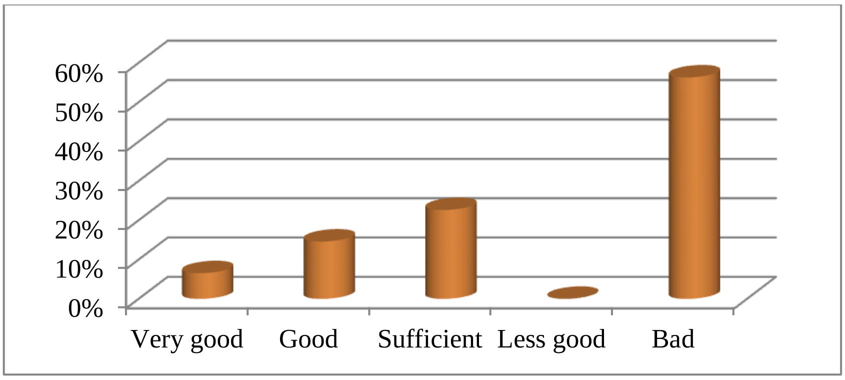


**Figure 4.** Profile of Chemical Literacy Ability on Topic 3.

Topic 3 contains the context of the B3 waste cooking oil that could potentially damage the environment. The results of the analysis show that the average student falls into the bad category. Students are weak in analyzing scientific information about understanding and disclosing the compound polarity using their structures and processes. Some students have a limited understanding of the concepts of polar covalent bonds and polarity, specifically students' understanding of the concept of electronegativity. This is in line with the research conducted by [27] which shows that many students have difficulty making meaningful connections between the concepts of electronegativity and polar covalent bonds.

Concept of students' understanding of polar covalent bonds and related concepts such as polarity and other electronegativitare y difficult to understand because they are blurry [28]. But some other students can distinguish whether the compound is polar or nonpolar based on the readings in the question. Students have an understanding that the oil cannot unite with water so that used cooking oil can become B3 waste (Hazardous and Toxic Material) which can potentially damage the environment. This is because in the process of learning educators has presented real-world situations into learning about the properties of the polarity of a compound. Learning that connects the concept of chemistry with problems in everyday life through learning approaches such as contextual approaches will produce meaningful chemistry learning [21]. Corresponds [29] statement that in developing the chemical literacy ability chemistry can be done by implementing learning-oriented material concepts to intra- problem students in their daily lives.

*3.4 Topic 4. Chemical bonding in aluminum foil (metal bonds)*

Topic 4 contains the context of the dangers of consuming food that is heated with aluminum foil. The results of the analysis of topic 4 chemical literacy ability are presented in Figure 5.

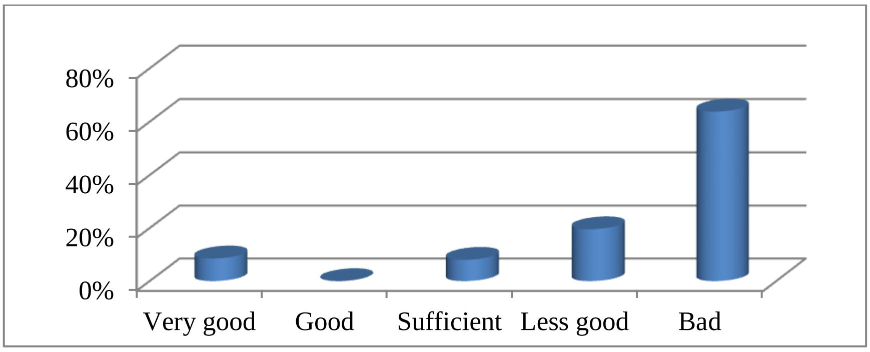


**Figure 5**. Profile of Chemical Literacy Ability on Topic 4.

The results of the analysis portray the results that are not much different from the previous 3 topics that the average student falls into the bad category. From the results of student answer analysis, only a few students can disclose the process of forming metal bonds appropriately. Some students can only express that metal bonds occur between metal elements, but cannot explain the process of forming metal bonds. This causes the students can not work on the next question on the nature of the metallic bond, which is the difference properties of metal compounds that are not easily broken compared to ionic compounds which are fragile. But other responses analysis results found that students could give other examples of metals that can be found in their daily lives. This proves that students' knowledge of metal ties in everyday life can provide meaningful learning in everyday life for students. In PISA 2015 it was described that scientific literacy skills of students would be more visible if they applied scientific knowledge in daily life.

This attainment of students' low chemical literacy ability proves that students are not familiar with chemical literacy-based questions where students are required to be too high in solving problems in the problem in questions so that students have difficulty in transferring the use of various chemical bond material concepts. One reason for the difficulties students experience in understanding the nature of matter is related to the various levels of representation used in chemistry learning to describe and explain chemical phenomena [19] [30]. Therefore teachers need more references in a learning to improve students' chemical literacy abilities. Chemical literacy can be developed by applying learning approaches and models. One of the learning models that can develop chemical literacy is a concept attainment model with a multiple representation approach in which this model can facilitate students' creative thinking which is one of the bases for developing chemical literacy [31].

## 4. Conclusion

Based on the results of this study, it can be concluded that the profile of chemical literacy abilities of 10th grade high school students on chemical bonding materials is still definetely low which falls into the bad category at 64%, indicated by many students are weak on the aspect of connecting and analyzing scientific information.

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