Comprehensive understanding of mole concept subject matter according to the tetrahedral chemistry education (empirical study on the first-year chemistry students of Technische Universität Dresden)

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Abstract. This research aims to apprehend: (1) the shape of tetrahedral chemistry education which is called the future of chemistry education, (2) comprehensive understanding of chemistry first-year students of Technische Universität Dresden according to the chemistry education’s tetrahedral shape on mole concept subject matter. This research used quantitative and qualitative; paper and pencil test and interview. The former was conducted in the form of test containing objective test instrument. The results of this study are (1) learning based on tetrahedral shape of chemistry education put the chemical substance (macroscopic), symbolic representation (symbol), and its process (molecular) in the context of human beings (human element) by integrating content and context, without emphasis on one thing and weaken another, (2) first-year chemistry students of Technische Universität Dresden have comprehensively understood the mole concept associated with the context of everyday life, whereby students are able to find out macroscopic information from statements that are contextual to human life and then by using symbols and formulas are able to comprehend the molecular components as well as to interpret and analyse problems effectively.

1. Introduction

The development of human life increases rapidly in line with the complexity of human life problems. Issues of energy resources, food crisis, global warming, environmental damage, and much more. With the increasing of the problems of human life, education, science and technology have also to be developed in order to be able for solving these problems.

Education is defined as the process of human’s reciprocal adjustment to nature, to his fellows, and to the ultimate nature of the cosmos [1]. Science and technology is an intellectual system of human life resulted from the education system in order for adapting to the challenges of nature. Education is an attempt to help children to perform the tasks of their life in order to be independent and responsible [2]. Therefore, education has also to be developed to contribute in the development of human life.

Chemistry is one of the subjects of science that has a big role and influence for human life. Applications of chemistry have contributed significantly to the progress of human civilization [3]. Chemistry education has a very important role in the development of chemistry from time to
time. Chemical education gives more attention to the provision of knowledge regarding the nature, components, changes and interactions between matter [4].

Today, a popular shape of chemistry education is a planar triangle. This shape has been used effectively to help us understand the three levels of learning, which are symbolic, macroscopic and sub-microscopic or molecular, required by students to understand chemistry. The three levels of learning form the three corners in the triangle. No one form is considered more dominant than the others, but each one complements the other. These forms of the subject are (a) the macro and tangible: what can be seen, touched and smelt; (b) the sub-micro: atoms, molecules, ions and structures; and (c) the representational: symbols, formulas, equations, mathematical manipulation and graphs [5].

![Figure 1. Tetrahedral Chemistry Education. Transformation of Chemistry Education](image)

However, various forces have shaped the teaching and learning of chemistry at the beginning of the 21st century. These include fundamental changes in chemistry as defined by new research areas; changes in our understanding on how students learn; application of computer technology and information in studying complex scientific phenomena; and external influences, such as global concerns about energy and water resources and environmental issues. In response to these forces, the shape of a triangle chemical education have to be emphasized into a tetrahedral shape, in which the fourth peak represents the human context in studying chemistry, that is the human element [6].

As a new shape of chemistry education, only has a little research been done on this topic. In contrast to the planar triangle chemistry education which has proven to be a prefix in the introduction to the first-year chemistry reader [7]. This triangle has also become a benchmark for national science education standards in the United States [8].

In chemistry education, there are several topics in chemical education that are important and fundamental discussions, ones is the concept of mole. The concept of mole is at the heart of all quantitative chemical calculations and is used by almost all laboratory chemistry experimental materials including limiting reagents, ideal gas law, stoichiometry, reaction equations, titration, electrolysis, chemical kinetics, thermodynamics, and others [9]. There may be no concept given in the first-year of learning chemistry is more important to be understood by students in addition to the concept because the concept of the mole is very essential for the study of the stoichiometry [10]. Although the concept of mole is an important concept in chemistry education, many studies reveal that the concept of mole is also a subject that is difficult to be understood. In many studies of the concept of mole, there are such a consensus that students are weak in understanding the concept of mole [11].

In connection with this, a survey with a large sample size including high school students (aged 16 years) to first-year students (aged 19 years) reported that there was an increase in the proportion of incorrect answers related to the concept of moles, where the answer did not match the definition of the IUPAC, so it was concluded that there was a superficial learning about the concept of mole [12]. Another study in the United States found the fact that second graders at high school and first-year students at the university did not have a comprehensive understanding of ’independent units’ in the definition of the concept of mole [13].
By combining two issues about the tetrahedral shape of chemistry education as well as the mole concept, researchers desire to examine the tetrahedral shape of chemical education on the concept of mole subject matter.

2. Research Methods
This research used an qualitative research design that is using data or empirical evidence to answer the problem. The research was conducted at Technische Universität Dresden, Germany. Research subjects were first-year chemistry students. We used a convenience sample in one lecture class.

The technique used to collect data is in the form of survey, interview and documentation. The survey was conducted in the form of questionnaire containing objective test instrument. Collecting data using a focus group interview gives richer and more research data. The curriculum documents represent a type of document analysis used in order to extract themes in regard to the topic being evaluated.

3. Discussion
The text of your paper should be formatted as follows:

Based on the results of cognitive test, first-year chemistry students at the Technische Universität Dresden (TUD) reaches a high enough score, which is the average correct answer correctly, is 75.96%; wrong answer 13.33%; and unanswered ones is 10.71%. The most difficult experience was in item number 6 which only are 44.44% of students able to answer correctly. While for item number 1 and 2, students are able to answer correctly with the highest percentage of 88.89%. Recapitulation of cognitive test results is presented in table 1.

In the cognitive test instrument, students read the material about Liquefied Petroleum Gas (LPG). Thus, students are expected to be more interested in learning chemistry because the cognitive test instrument has a correlation with everyday human life.

| Item Number | Percentage (%) |
|-------------|----------------|
| Correct     | Wrong          | Unanswered |
| 1           | 88.89          | 11.11      | -            |
| 2           | 88.89          | 11.11      | -            |
| 3           | 86.67          | 13.33      | -            |
| 4           | 64.44          | 15.56      | 20.00        |
| 5           | 86.67          | 13.33      | -            |
| 6           | 44.44          | 20.00      | 35.56        |
| 7           | 82.22          | 17.78      | -            |
| 8           | 68.89          | 11.11      | 20.00        |
| 9           | 73.33          | 8.89       | 17.78        |
| 10          | 80.00          | 6.67       | 13.33        |
| 11          | 71.11          | 17.78      | 11.11        |
| Average     | 75.96          | 13.33      | 10.71        |

In the beginning of the instrument (item number 1 and 2), students are simulating to read a brochure about a gas product, which is bought from a company; they therefore have to look for some information from the brochure. After finding the mass information of each gas and its mole mass, then students then look for the mole value of each gas.
item number 1 and 2 involve 4 elements simultaneously in tetrahedral chemistry education, which are macroscopic, molecular, symbolic and human elements. Macroscopic is what can be seen, touched and kissed. In this case, it includes gases in LPG cylinder, because the mass can be calculated using the balance. Molecular or sub-micro is atoms, molecules, ions and structures. The propane molecules and the butane molecules inside the LPG cylinder including the amount of each molecule are molecular components that cannot be identified directly. The representational is symbols, formulas, and equations used by students so that students can find the amount of substances of each molecule inside the cylinder. While the LPG theme is the human element because LPG is very wide in everyday life.

In this part, we emphasized a new dimension on teaching chemistry to pay attention on the role of chemistry in everyday life. It is known that students who are able to answer correctly on item number 1 and 2 have understood comprehensively the concept of mole associated with the context of everyday life, whereas students are able to find macroscopic information from statements that are contextual to human life then by using symbols and formulas can understand the molecular components.

Item number 3 and 5 aim to determine the level of students' understanding on the definition of mole. These items were developed based on Menis & Novick's research [14]. Item number 4 is aims to calculate the amount of substances by the elementary entities of the atoms according to Avogadro's hypothesis.

Item number 6 is calculation of gases volume related to the amount of substance according to Avogadro's hypothesis and the ideal gas law. In this case, students have to calculate the volume of gases inside the LPG cylinder if the gases occupy a large blank space. Item number 7 aims to determine the level of students' understanding on the state of the molecules inside LPG cylinder. Item number 8 discusses the relationship among the mass of matter, the amount of substances and the molar mass. Interestingly, beside determining the amount of substances, students also got an interesting information related to the history and facts of the unpleasant odor from LPG cylinder when it leaks. Item number 9, 10 and 11 aim to understand the use of the mole concept on the quantitative calculation of stoichiometry. Students have to not only quantitatively calculate, but also understand the use of LPG and other fuels (kerosene and methane) in everyday life.

All items in this study involve the macroscopic, molecular, symbolic and human element. In the last part of the cognitive test, students are given a text about the issue of global warming. This is certainly relevant to the theme of LPG because the combustion reaction of fossil fuels, including LPG, kerosene, methane and much more, produce carbon dioxide. Carbon dioxide can be concentrated in the atmosphere. In fact, carbon dioxide is the main cause of the greenhouse effect, which is able to capture and re-radiate infrared radiation to the surface of the earth. Thus, the increased concentration of carbon dioxide in the atmosphere can increase the temperature of the earth's surface.
Figure 3. Explanation of Global Warming Issue in The Last Part of The Cognitive Test

Item number 12 is able to attain students' responses or comments after doing cognitive test for items number 1 through number 11. Students are required to illustrate an image that represent their comments or responses. It is expected that students be able to have an understanding related to the human elements.

Figure 4. Image Illustrated by The First Student

Figure 5. Image Illustrated by The Second Student

The first student illustrated an image in figure 4 where the surface temperature of the earth is measured using a giant thermometer showing a high temperature. This indicated that the first student is interested in the information at the last part of the cognitive test explaining the rising of earth surface’s temperature. Similar to first student exposure, the second student tried to give the same explanation but with a different illustration in figure 5.

Figure 6. Image Illustrated by The Third Student

The third student interested in the issue of the amount of carbon dioxide (CO$_2$) produced from fossil fuels combustion in figure 6. Based on his observations related to examples which appear in the cognitive test (item number 9,10 and 11), he concluded that the use of methane (CH$_4$) is better than LPG ($C_3H_8$ and $C_4H_{10}$) and kerosene ($C_{12}H_{26}$) because of less carbon dioxide produced.
The image by the fourth student in figure 7 indicates that he was interested in the history of the gas explosion at London School of New London in Texas, USA. The explosion was caused by leakage of natural gas pipeline explained in the item number 8. This explosion also brought to a new invention of using odor to detect gas leakage.

![Image](https://via.placeholder.com/150)

**Figure 7. Image Illustrated by The Fourth Student**

The fifth student illustrated all the things obtained during the completion of the cognitive test in figure 8. He accommodated all the information from LPG composition, gas properties in LPG, usefulness, as well as the impact caused by the using of LPG as fuel.

![Image](https://via.placeholder.com/150)

**Figure 8. Image Created by The Fifth Student**

In this research, interview was conducted using focus group interviews. Subjects in this focus group were the first-year chemistry student. Focus group interviews were conducted to acquire informations on: (1) the difficulties experienced by the first-year chemistry students during the cognitive test; and (2) understanding from cognitive test related to everyday life.

Based on interviews and discussions, it is known that the first-year chemistry student at the Technische Universität (TU) Dresden suffered two difficulties during the cognitive test. The first is item number 6 of the questionnaire turned out to be quite difficult for the students, since they had not learned about ideal gases, yet. The second issue was a language problem. The TU Dresden students had difficulties with understanding English that was quite surprising and embarrassing for us and tells us that this needs to be changed.

In addition, the results of interviews and discussions shows that students were very interested in learning many things related to the using of LPG in everyday life. The students also became aware that the use of fossil fuel energy such as gases and oils could affect the environment. This is due to the combustion of fossil fuels to produce carbon dioxide. This carbon dioxide is the main gas enhancing the greenhouse effect that brings a rising of global surface temperature or global warming. Thus, students understood not only the concept of mole cognitively, but also the use of LPG in many countries as well as became aware of the issue of global warming caused by human activities in utilizing fossil fuels as an energy source.

Based on these results, it can be concluded that the first chemistry student of Technische Universität Dresden has comprehensively understood the concept of mole associated with the context of everyday life whereas students are able to find macroscopic information from statements that are
contextual to human life then using symbols and formulas are able to understand the molecular components. Thus, students have gained a coherent understanding of the definition of the concept of mole and the importance of interpreting chemical phenomena as well as the ability to analyse mole-related issues effectively.

4. Conclusions
Based on the results of the research, it can be concluded that (1) learning based on tetrahedral shape of chemistry education put the chemical substance (macroscopic), symbolic representation (symbol), and its process (molecular) in the context of human beings (human element) by integrating content and context, without emphasis on one thing and weaken another, (2) first-year chemistry students of Technische Universität Dresden have comprehensively understood the mole concept associated with the context of everyday life, whereby students are able to find out macroscopic information from statements that are contextual to human life and then by using symbols and formulas are able to comprehend the molecular components as well as to interpret and analyse problems effectively.

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