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Analysis of Students' Mental Models in Learning The Periodic System of Elements Using 3D Representations

Rezti Wahyu Noviyanti^{1,*}, Yuli Rahmawati², Yussi Pratiwi³

¹Chemistry Education Study Program, Faculty of Mathematics and Natural Sciences, Universitas Negeri Jakarta, Jl. R. Mangun Muka Raya No.11, East Jakarta City, Jakarta 13220, Indonesia

²The Embassy of the Republic of Indonesia in Canberra, 8 Darwin Avenue, Yarralumla, ACT 2600, Canberra, Australia

³Chemistry Study Program, Faculty of Mathematics and Natural Sciences, Universitas Negeri Jakarta, Jl. R. Mangun Muka Raya No.11, East Jakarta City, Jakarta 13220, Indonesia

*Email: : reztinoviyanti01@gmail.com

Abstract

This study aims to analyze the mental model of students in learning the periodic system of elements using 3D representations. This research was conducted in the odd semester of the 2022/2023 academic year. The research subjects were 36 students of class XB SMAN 54 Jakarta. This study used qualitative research methods. Data collection techniques through mental model tests, interviews, reflective journals, and classroom observations. The students' mental models were analyzed in three stages, namely engage, explore, and explain. The students' mental models are categorized into three, namely scientific, synthetic, and initial mental models which are viewed from the three levels of macroscopic, submicroscopic, and symbolic representations. The results showed that class XB had three categories of mental models, namely scientific mental models with an overall average of 70.86%, synthetic mental models with an overall average of 17.54%, and initial mental models with an overall average of 11.60 %. Mental models are formed from the thoughts and experiences of students who previously had, teacher explanations, 3D representation media, and handbooks or other sources.

Keywords: 3D representations, mental model, periodic system of elements

Introduction

Chemistry is a branch of natural science that studies the properties of matter, material structure, material changes, and the energy that accompanies material changes (Shao, 2024). Chemistry has an important role in advancing the development of thought, because through chemistry the little things in life can be explained logically. Knowledge of basic aspects of chemistry involves understanding the periodicity in the periodic table of elements so that the properties of an element can be predicted on the basis of similarities in a group and variations throughout the period.

The periodic system of elements is the basis of chemistry where if the periodic system of elements has not been mastered by students, it will be difficult to master the concept of chemical matter next. The topic of periodic system material is quite complex, students often have difficulty in determining the basis for grouping the theories contained in it (Schmidt & Würthner, 2020).

The concept of chemistry in learning needs to be represented to make it easier for students to understand the learning material. Representation in chemistry consists of three levels, namely: macroscopic, submicroscopic, and symbolic (Schwedler & Kaldewey, 2020). Macroscopic representation describes in real terms what is in the daily life of students (Mittelmeier et al., 2025). Submicroscopic representations are representations described at the particle level, such as: electrons, protons, neutrons, atoms, elements, and molecules (Pfeil-Gardiner et al., 2024). Symbolic representation is a representation related to symbols, stoichiometry, graphs, diagrams, and mathematical equations (Schwedler & Kaldewey, 2020). The three levels of chemical representation integrated in learning can improve the modeling ability and train students' mental activities. Mental activity will produce a mental model which is essentially a student's understanding of the concept (Wright & Oliver-Hoyo, 2020).

A mental model is a concept in the minds of learners as a result of perception, imagination, experience, and interaction or understanding of abstract representations of non-visualized circumstances that are used to describe and explain phenomena (Bidlake et al., 2025). The mental model represents the learner's understanding of the features of the outside world and forms the learner's reasoning center. Mental models can help shape behavior and set approaches to solve problems as well as complete tasks. The mental model develops during the learning process and can be influenced by various factors, including the learning model, teaching materials, media or representations used by teachers in learning, and from the students themselves.

The results of observations and interviews conducted on October 7, 2022 with teachers and students of class XB of SMA Negeri 54 Jakarta show that there are still prerequisite concepts, namely the concept of atoms that are difficult to understand and the use of representations in the form of learning videos that are ineffective because they contain several foreign words that students are reading and hearing for the first time. In addition, students tend to memorize chemistry by heart. After the initial test was carried out, it was shown that students still experienced misconceptions in explaining the definition of atoms, the particles that make up atoms, and writing down elemental symbols. One of the technological developments in the world of education that affects the evolution of learning styles from verbal to visual is the use of 3D representations. A 3D model is a representation of the actual physical properties of an object that can be manipulated, animated, and scaled. The use of 3D representations offers a step-by-step approach to learner-centered learning (Moore, 2024). Based on this, the researcher is interested in obtaining an overview of students' understanding by analyzing the mental model of students in the learning of the periodic system of elements using 3D representations, so that the mental profile of the student model is obtained.

Metode

This study uses a qualitative methodology, so that the process and meaning from the subject's point of view, namely 36 students of class XB SMAN 54 Jakarta, are more highlighted. Data collection was carried out from October to November 2022 for the 2022/2023 school year. Initial activities were carried out to develop instruments and understand the context of the research to be carried out. Data collection in this study was carried out through writing-drawing techniques on student worksheets and final tests of the periodic system of elements, interviews, observations, and reflective filling in journals. The implementation of research on elemental periodic system learning uses the Learning Cycle 3E model. Furthermore, in the final stage, data coding and analysis of students' mental model profile data were carried out from three levels of chemical representation, namely: macroscopic, submicroscopic, and symbolic. The data analysis technique in this study uses a model.

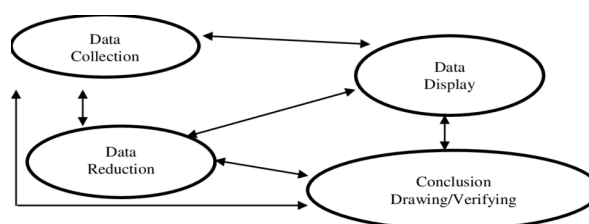


Figure 1. Framework for the relationship between data analysis and Milles & Huberman data collection

The criteria for the validity of the data used in this study are the degree of credibility, consisting of: prolong engagement, persistent observations, continuous observation of every change in students from the beginning to the end of the study (progressive subjectivity), and review of the mental model data that has been obtained (member checks).

Results and Discussion

Learning with the 3E Learning Cycle Model Using 3D Representations

The learning process in this study is divided into three stages:

Engage

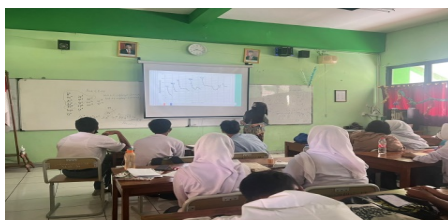


Figure 2. Engage Stage

In the engage stage, the aim is to capture students' attention, encourage their abilities, and help them access the prior knowledge they already possess (Palalas et al., 2024). The engage stage that has been conducted during the research can enhance students' motivation to learn more deeply about the learning material that will be studied in each session. This is in accordance with Kelly et al. (2024) which states that at the engage stage, the teacher aims to understand the prior knowledge of the students and identify the possibility of misconceptions. This student-centered stage becomes a period of motivation that can create a desire to learn more broadly about the topic to be studied.

Explore



Figure 3. Explore Stage

In the explore stage, it aims to stimulate students' curiosity and develop the need to know something (Palalas et al., 2024). Teachers provide opportunities for students to explore their knowledge from various sources, namely chemistry books, the internet, and applications and the web. Then, at this stage, the teacher invites students to use 3D representations. Some students when shown 3D representations feel interested, so as to increase students' motivation to learn and make it easier for students to understand the material, especially in submicroscopic representations, as in Figure 4 there is a student who draws a 3D representation.



Figure 4. Students who draw a 3D representation of the periodicity of atomic radii properties in an elemental periodic table

This discovery is in accordance with the results of research that show that the use of 3D representation is successful in attracting students' interest and increasing their motivation to learn (Favier et al., 2024; Ka et al., 2025). The exploration stage that has taken place during the research causes a mental imbalance that leads to the development of high-level reasoning, this is evidenced by the activeness of students in learning. The student's activeness in asking and answering the teacher's questions is an indicator of the student's readiness to take the next stage of learning, namely the explain stage (Palalas et al., 2024).

Explain

In the explain stage, students are given the opportunity to explain and present the results of problem solving that have been carried out in the previous stage. Teachers play the role of facilitators and validators by strengthening the conclusions of learning outcomes that have been delivered by students.

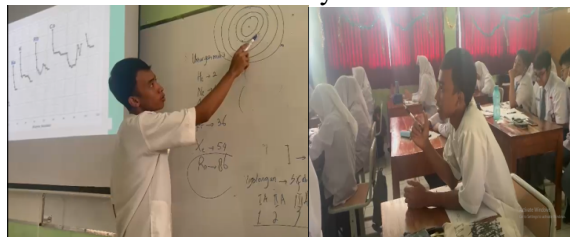


Figure 5. Explain Stage

The explain stage that has taken place during the study shows that students are able to explain the results of their exploration. At each meeting, there is a development of the level of thinking. Students who initially did not understand the learning material became more understanding. This is in line with the statement (Palalas et al., 2024) in the explain stage the teacher guides the learner towards a coherent and consistent generalization, helps the learner with different scientific vocabulary, and the questions given by the teacher help the learner use the vocabulary to explain the results of their exploration. In addition, it is also in accordance with the results of research conducted by Adler et al. (2024) that at the explain stage, students can explain their understanding and there is a change in understanding from those who initially did not understand a concept to understand the concept of the material being studied.

Students' Mental Models in Elemental Periodic System Learning

The mental model in this study is the mental model of Jansoon and Kurnaz. Mental models are viewed based on macroscopic representations, submicroscopic representations, and symbolic representations. In this study, to measure the mental model of class XB students, it is categorized into 3, namely scientific, synthetic, and initials. According to Pedrera et al. (2025), the mental model of the scientific category if the statements of students in answering are in accordance with scientific knowledge, the synthetic mental model if most of them are true in accordance with scientific knowledge and a small part is wrong, and the initial mental model if most of the students' statements are wrong and only a small part of the answers are empty.

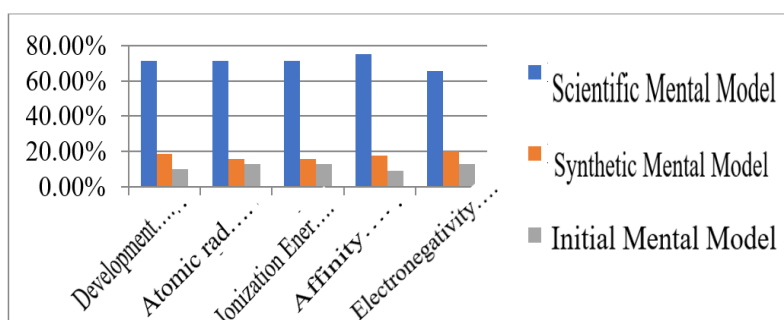


Figure 6. Histogram of Students' Mental Models

In this study, the highest mental model of students is the scientific mental model. The scientific mental model is the highest because most students can write and describe macroscopically to submicroscopic and symbolic representations, but there are still a small number of students who experience misunderstandings. The three mental models formed in this study are influenced by several factors, namely: students' thoughts and experiences that they have beforehand, teacher explanations, 3D representation learning media used during learning, handbooks or other sources.

This is in accordance with previous research which states that the mental model is formed from the teacher's explanation during learning, the students' understanding of concepts, the linguistic differences between scientific terms and everyday words or sentences, and the representations used by teachers in learning (Borders et al., 2024). In addition, according to research that states that students' mental models are also influenced by learning models, approaches or strategies, learning media, and textbooks used by teachers in learning (Floyd & Spratz, 2024). The following is a breakdown of the two mental models based on representation and category:

Mental Model on Sub-Matter of Development and Components of the Periodic Table of Elements

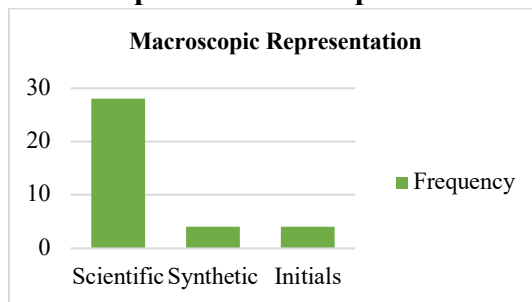


Figure 7. Histogram of Macroscopic Representation of Development and Components of the Periodic Table of Elements

The use of 3D representation in learning affects students' understanding, this is proven from the reflective notes of students' journals:

"....., because it is a new and exciting thing. Also, the elements are more visible by using 3D representations."

(Student 10, Reflective Journal, October 28, 2022)

The scientific mental model of students is reviewed from macroscopic representations:

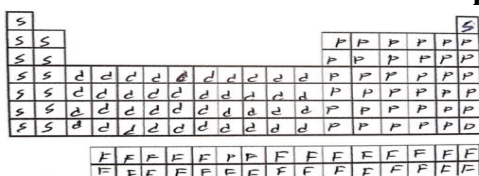


Figure 7. Macroscopic Representation of Scientific Category

In the picture that shows the scientific mental model, students can determine the location of the blocks s, p, d, and f by writing the symbols s, p, d, and f on the blank periodic table correctly. This corresponds to as follows:

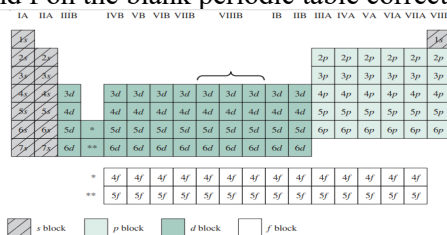


Figure 8. Place blocks s, p, d, and f

Furthermore, the scientific category is reviewed from the macroscopic representation shown through the depiction according to the illustration of the sodium bromide solution found in the beaker:

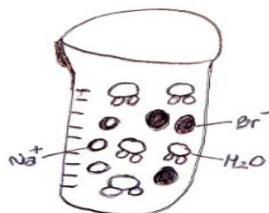


Figure 9. Macroscopic Representation of Scientific Category

Students describe a beaker containing a solution of sodium bromide, and provide information about positively charged sodium ions, negatively charged bromine ions, and water with the correct symbols written according to those in the periodic table of elements. The students described Br^- as greater than Na^+ and O greater than H. This is in accordance with Zhang et al. (2024) which states that in representing at the macroscopic-submicroscopic level such as particles in an aqueous solution it is important to pay attention to the size and writing of atoms.

Students' synthetic mental models are reviewed from macroscopic representations:

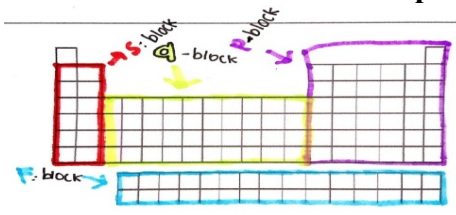


Figure 10. Macroscopic Representation of Synthetic Categories

Based on Figure 10, there is a misconception that the hydrogen element box is not located in block s and the helium element box is located in block p. The element hydrogen is not an element of the alkali group because it has different properties from the elements of alkali metals, but the element hydrogen is located in the block s (Lynch et al., 2024). The property that distinguishes the element hydrogen from the element of alkali metal is that hydrogen is a gas but the element of alkali metal is a solid. Hydrogen is a smaller gas that has a higher electronegativity than alkali metals. To complete the outermost valence shell, hydrogen requires one electron and alkali metal requires seven electrons (Wang et al., 2024). Whereas, Helium is located in block s because it has 2 valence electrons in the s orbital.

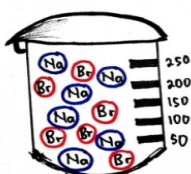


Figure 11. Macroscopic Representation of Synthetic Categories

Students described a chemical cup containing sodium and bromine, and provided information about Na and Br that were not equipped with the content and the size of both was the same. This is not in accordance with the illustration in question, namely the sodium bromide solution.

The mental model of learners' initials is reviewed from a macroscopic representation:

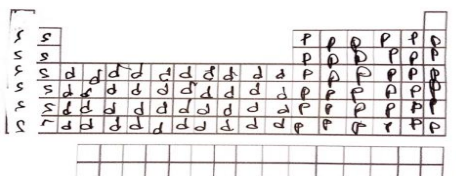


Figure 12. Macroscopic representation of Initial Category

Students with the initial mental model do not solve the problem of determining the location of blocks s, p, d, and f.

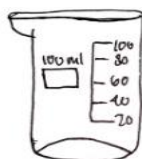


Figure 13. Macroscopic representation of Initial Category

The students only described an empty beaker.

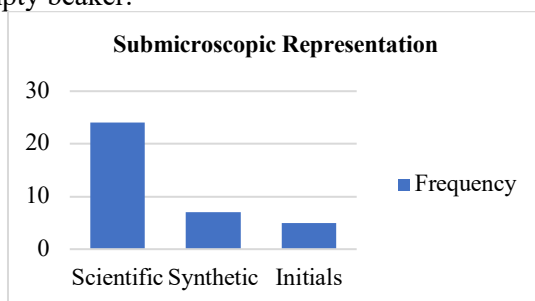


Figure 14. Submicroscopic Representation Histogram of Development and Components of the Periodic Table of Elements

The scientific mental model of students is reviewed from submicroscopic representations:

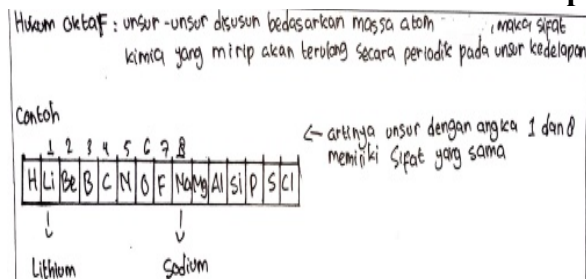


Figure 15. Submicroscopic Representation of Scientific Categories

Students can explain the development of the John Alexander Reina Newlands periodic table correctly. This is in accordance with John Alexander Reina Newlands stated that if the known elements are arranged according to their atomic mass, then each eighth element has properties similar to the first, Newlands' law is not suitable for the elements after calcium.

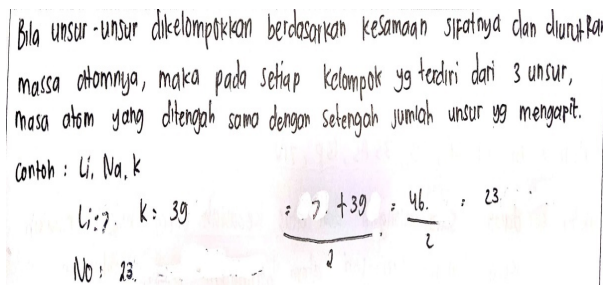


Figure 16. Submicroscopic Representation of Scientific Categories

Students can explain the Dobereiner's Triade law correctly. This is in accordance with Hsieh et al. (2024) Dobereiner's Triade law which states that when elements of the same properties are placed in the order of their relative atomic mass increase, the atomic mass of the middle element is equal to the average atomic mass of the other two elements. However, this rule does not apply to all elements.

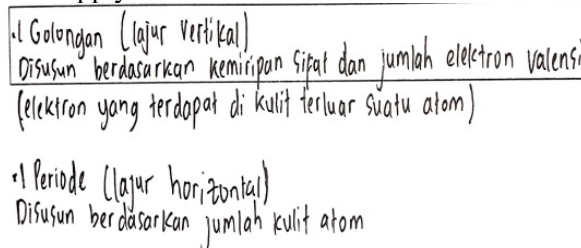


Figure 17. Submicroscopic Representation of Scientific Categories

Students can correctly explain what is meant by groups, periods, and the reasons underlying the elements placed in one group and in one period. This is in accordance with Hsieh et al. (2024) that a group is a vertical row in the periodic table of elements, elements that are arranged in one group because they are similar in nature and have the same valence electrons, while periods are horizontal rows in the periodic table of elements, elements that are arranged in one period because they have the same number of shells.

Students' synthetic mental models are reviewed from submicroscopic representations:

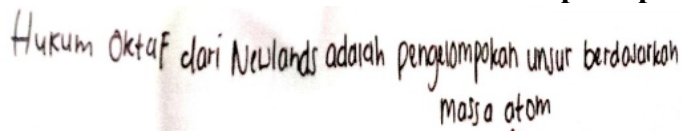


Figure 18. Submicroscopic Representation of Synthetic Categories

Students explain incompletely about the octave law. Students' knowledge is only limited to knowing if the octave law is a grouping of elements based on atomic mass.

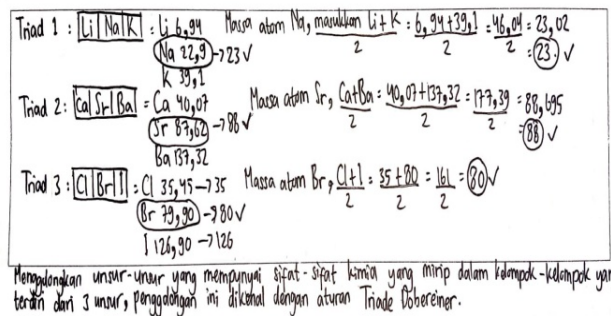


Figure 19. Submicroscopic Representation of Synthetic Categories

Students are able to name elements that are in accordance with the rules of the Triade Dobereiner, but in writing students experience a slight error that is written is atomic weight, then the average result is rounded and the student's explanation is incomplete, this is because students do not understand the difference between atomic weight and atomic mass. Furthermore, the third synthetic category is reviewed from the submicroscopic representation shown through the students' knowledge of the class, period, and underlying reasons that the elements are placed in one group and in one period:

"A group is a group of elements located in the same vertical column. Whereas, periods are groups of elements located in the same horizontal column"

(Student 1, LKPD, October 28, 2022)

Students only give answers to the understanding of groups and periods without being accompanied by the underlying reasons that the elements are placed in one group and in one period.

The mental model of learners' initials is reviewed from submicroscopic representations:

"Newlands' law of octaves is the grouping of elements based on atomic mass, the elements are arranged in groups of seven elements"

(Student 2, LKPD, October 28, 2022)

Students explain incompletely and assume that the octave law consists of seven elements.

unsur - unsur dikelompokkan berisi tujuh unsur yang memiliki sifat yang sama

Figure 20. Submicroscopic Representation of Initial Category

Students assume that Newlands groups elements containing seven elements, and that all seven elements have the same properties.

"In the same group of shells, in the same period the outermost electron or valence electron"

(Student 7, Interview, October 21, 2022)

The answer submitted by the students is reversed, the correct concept is that elements in one group have the same properties and valence electrons, while elements in one period have the same number of shells.

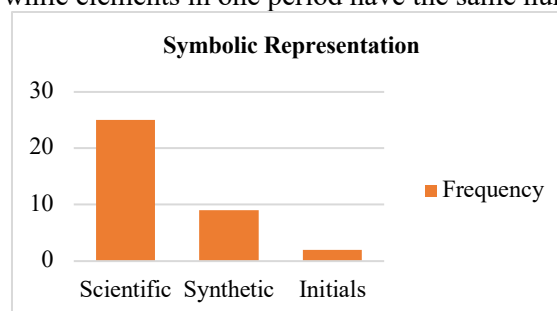


Figure 21. Histogram of Symbolic Representation of Development and Components of the Periodic Table of Elements

The scientific mental model of students is reviewed from symbolic representations:

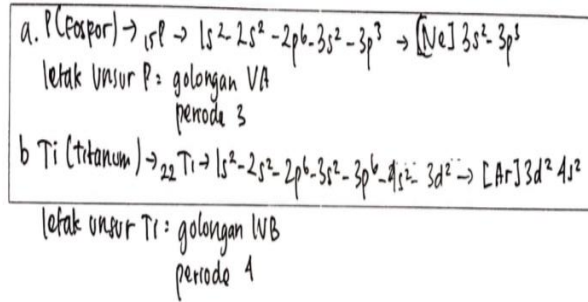


Figure 22. Symbolic Representation of Scientific Categories

Students can correctly determine the location of phosphorus and titanium elements using electron configurations. Students write down the electron configuration in its entirety and shorten the electron configuration using noble gas group elements. This scientific category corresponds to:

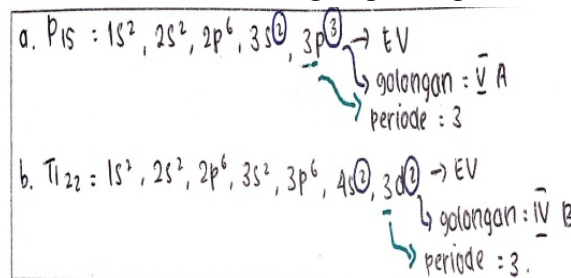
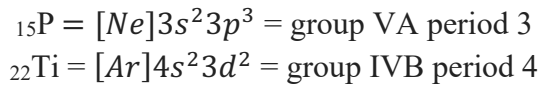


Figure 23. Symbolic representation of synthetic categories

Students misdetermined the location of the period of the IT element. The learner assumes the period is seen from the major quantum number located last in the electron configuration.

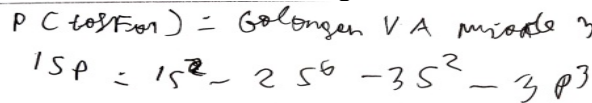


Figure 24. Symbolic representation of initial categories

Students are incorrect in writing down the electron configuration and are unable to determine the location of the element.

Mental Model on Atomic Radius Submatter

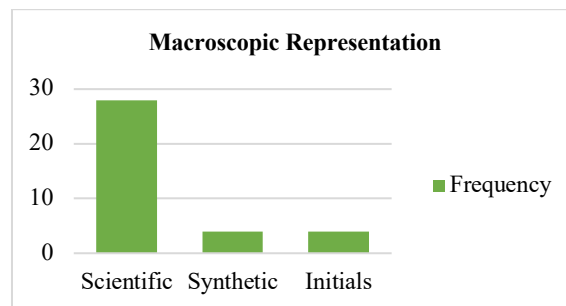


Figure 24. Histogram of Macroscopic Representation of Atomic Radius

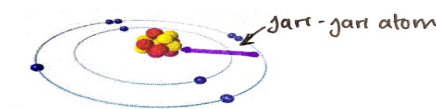


Figure 25. Macroscopic Representation of Scientific Category

Students represent that the atomic radius is the distance from the atomic nucleus to the outermost electron or the weakest bonded electron. This scientific category corresponds to atomic radius is the distance from the nucleus of the atom to the outermost electron orbital.

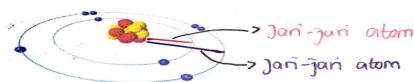


Figure 26. Macroscopic Representation of Synthetic Categories

Students experience the misconception that the radius of an atom is the distance from the nucleus of an atom to all atomic shells.

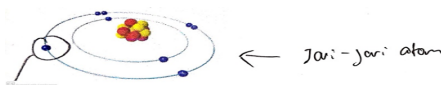


Figure 27. Macroscopic representation of Initial Category

Students showed that the atomic radius is the distance from the left atomic shell to the right atomic shell.

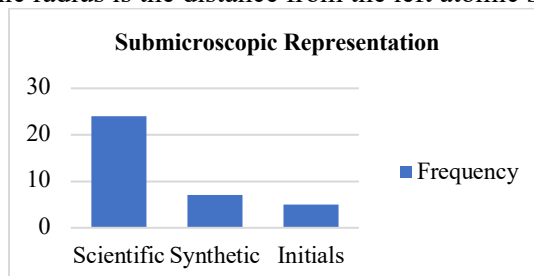


Figure 28. Histogram of Submicroscopic Representation of Atomic Radius

"In one group, from top to bottom, the atomic radius increases due to the influence of the increase in the number of atomic shells which is the dominant factor compared to the increase in the core charge"

(Student 34, LKPD, November 4, 2022)

The students conveyed the correct concept of the periodicity of atomic radii that in one group from top to bottom, the atomic radius increases in size due to the factor of increasing the number of skins. This is in accordance with Yang et al. (2024) which states that the atomic radius increases in a group from top to bottom due to the increase in the number of shells and decreases in a period from left to right as the nuclear charge increases so that electrons are more attracted towards the nucleus causing the atom size to shrink.

"The radius of an atom in a period from left to right, the radius of the atom tends to get smaller"

(Student 3, LKPD, November 4, 2022)

Students can correctly answer the periodicity of the atomic radius in a period, but do not explain what causes the periodicity of the atomic radius in a period from left to right to tend to shrink.

Dalam 1 golongan maka semakin ke bawah semakin besar.

Figure 31. Submicroscopic Representation of Synthetic Categories

Students can correctly answer the periodicity of atomic radii in one group, but do not explain what causes the periodicity of atomic radii in one group from top to bottom tends to be larger.

"In my opinion, what I have learned, the farther you have been so far, the wider the distance will be, the bigger you will be in one period because the distance from the core to the outermost shell or the outermost electron is getting bigger, then vice versa, if in one group of atoms the radius from top to bottom it will be smaller"

(Student 20, Interview, November 8, 2022)

Students are wrong in explaining the periodicity of atomic radii in one group and in one period and do not provide an explanation that causes the periodicity of atomic radii to occur. The tendency in one group from top to bottom is that the atomic radius increases while in a period from left to right the atomic radius gets smaller.

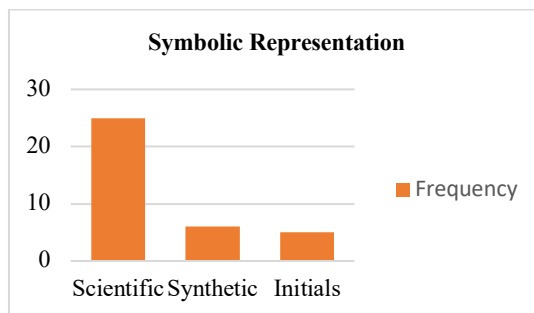


Figure 29. Histogram of Symbolic Representation of Atomic Radius

"The order is based on the atomic radius of the smallest: 7N – 6C – 5B – 4Be – 3Li. The element is in one period, the more to the right the location of an element in the periodic table, the smaller the atomic radius. Because the charge of the atomic nucleus is increasing, but the number of shells remains the same, so the electrostatic attraction increases."

(Student 8, Final Test, November 18, 2022)

Students are able to correctly sequence the periodicity of the atomic radius in a period accompanied by an explanation that the more to the right the location of the element in the periodic table, the smaller the atomic radius, because the charge of the atomic nucleus is more and the number of shells is fixed so that the electrostatic attraction increases. This is in accordance with (18) which states that in one period the radius of the atom decreases as the charge of the nucleus increases so that electrons are more attracted towards the nucleus causing the size of the atom to decrease.

"The radius of Na is larger than that of Na⁺, the radius of the cation is smaller than the radius of its neutral atom due to the release of one electron, the repulsion between the electrons will be reduced but the core charge will remain the same, so the electron cloud will shrink miss"

(Student 19, Interview, November 4, 2022)

Students can correctly determine the largest ion radius equipped with an explanation. This is in accordance with Yang et al. (2024) which states that the cation is smaller than its neutral atom because the release of one electron causes the shielding effect caused by the repulsive force between the electrons to decrease but the core charge remains the same, so the electron cloud shrinks. Thus the correct ion radius is $\text{Na} > \text{Na}^+$.

7N, 6C, 5B, 4Be, 3Li

Figure 30. Symbolic representation of synthetic categories

Students were able to correctly sequence the periodicity of atomic radii in a period from the smallest to the largest but did not explain what caused the periodicity to occur.

"The order is from the larger to the smaller Na then Na⁺. If for the reason I don't know, ma'am, I only remember what was said that the neutral atom has bigger fingers than cations"

(Student 25, Interview, November 4, 2022)

The students were correct in determining the largest ion radius but were unable to explain the reason why the answer they conveyed about the neutral atomic radius being larger than the cation radius. Next, the initial category is reviewed from the symbolic representation:

"The small Na is then the largest is Na⁺ because if for example the largest + is like a positive math, it means that the score is big, the same for example, the answer is usually that the teacher if he gives a grade, there is also an A+, which is very good compared to A. So the smaller Na is compared to Na⁺"

(Student 20, Interview, November 12, 2022)

Students are wrong in determining the periodicity of ion radius, students assume that cations have larger radii than neutral atoms. This misunderstanding can occur because students analogize it just like mathematics that the more positive, the greater.

Mental Model on Ionization Energy Submatter

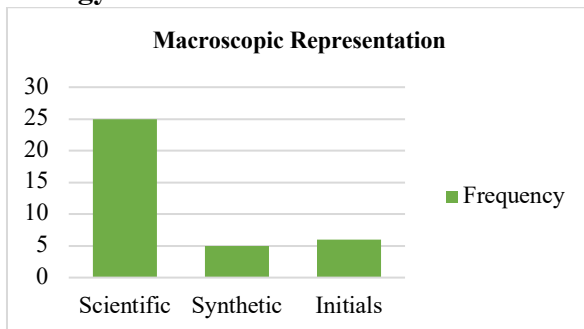


Figure 31. Histogram of Macroscopic Representation of Ionization Energy

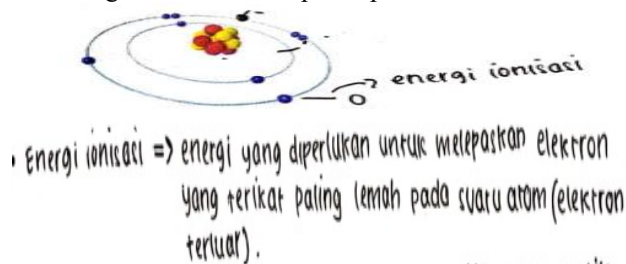


Figure 32. Macroscopic Representation of Scientific Category

Students are correct in representing and explaining the meaning of ionization energy. It is in accordance with Yang et al. (2024) that ionization energy or ionization potential is the energy required to release electrons from atoms or gas ions.

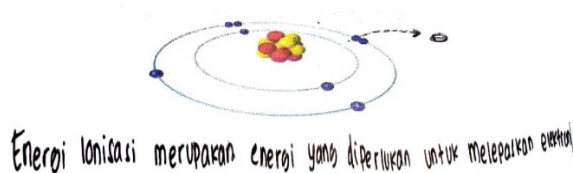


Figure 33. Macroscopic Representation of Synthetic Categories

The students are correct in representing but answering incompletely, not explaining that the released electron is the weakest bonded electron. Next, the initial categories are reviewed from the macroscopic representation:

"....., the ionization energy is the same negative energy, the same positive energy, so it is calculated from the most energy, it is ionization energy"

(Student 20, Interview, November 4, 2022)

Students are wrong in explaining the meaning of ionization energy, students consider that energy, both positive and negative in large quantities, is ionization energy.

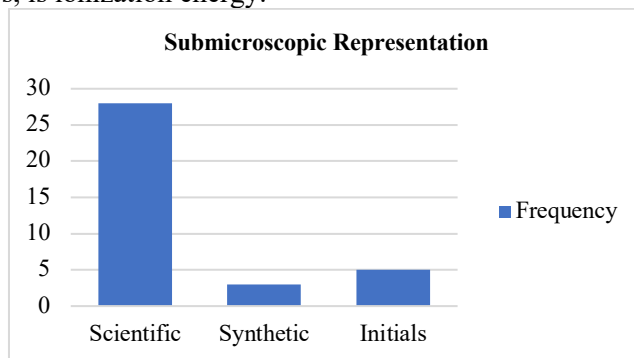


Figure 34. Histogram of Submicroscopic Representation of Ionization Energy

Dalam satu golongan, dari atas - bawah energi ionisasi semakin kecil
 dan jari-jari atom bertambah besar, sehingga daya tarik inti
 terhadap elektron terluar semakin lemah dan energi ionisasi
 berkurang.

Figure 39. Submicroscopic Representation of Scientific Categories

"If in one period from left to right it increases because the nuclear charge increases and the atomic radius decreases, the electrostatic pull of the atomic nucleus with the electrons in the outer shell is getting stronger, so to release 1 outermost electron requires more and more energy, ma'am. If those in one group from top to bottom decrease because the number of shells increases, the attraction of the nucleus with the outermost electrons is getting weaker."

(Student 17, Interview, November 21, 2022)

Students can explain the periodicity of the properties of the first ionization energy along with its explanation correctly. This is in accordance with (18) that the first ionization energy trend in a period occurs an increase in ionization energy along with the increase of the core charge. Meanwhile, in one group there is a decrease in ionization energy.

energi ionisasi dalam
 satu golongan (dari atas kebawah) energi
 ionisasi semakin mengecil

Figure 35. Submicroscopic Representation of Synthetic Categories

Teacher: "What is the periodicity of the properties of ionizing energy in one group and in one period?"

Student 19: "In one period the ionization energy is getting bigger, if the one in one group of ionization energy seems to be getting smaller"

Teacher: "What causes the periodicity to occur?"

Student 19: "I only know about periodicity, ma'am, for the reason underlying periodicity I am still confused and do not understand"

Teacher: "Okay, now try to explain the exception of the periodicity of ionization energy that you know?"

Student 19: "What I explained earlier was that there was a trend break in the second period of boron and oxygen"

Teacher: "Please explain what caused the trend break?"

Student 19: "I still don't really understand the orbital electron 2s 2p"

(Student 19, Interview, November 4, 2022)

Students are correct in conveying their understanding of the periodicity of ionization energy first in one group and in one period, but are unable to provide an explanation because they still do not understand the concept of periodicity of ionization energy properties. In addition, students are aware that there is a trend break in the second period of element B but still do not understand much about what causes the trend break. The trend break in the second period occurred because boron was the first atom to have an electron in a higher 2p orbital that was somewhat protected by the 2s electron, the 2p electron of boron was more easily released than the 2s electron of beryllium, so boron had a lower ionization energy.

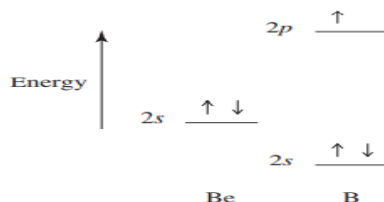


Figure 36. Diagram of beryllium and boron energy levels

Meanwhile, the pause in the oxygen ionization energy trend occurs because in nitrogen all 2p orbitals are half filled



Figure 37. Orbital 2p nitrogen

Nitrogen has an atomic number of 7 whereas oxygen has an atomic number of 8 which means the number of electrons between nitrogen and oxygen has a difference of 1. In oxygen 1 electron is placed in the 2p orbital which has been half full, to put two electrons into the same orbital it takes extra energy. It takes a little more energy to pair electrons, whereas to release electrons in pairs, less energy is needed so there is a gap in the trend of ionization energy $N > O$.



Figure 38. Orbital 2p oxygen

Dalam 1 golongan maka semakin ke bawah semakin besar.

Figure 39. Submicroscopic Representation of Initial Category
"Ionization energy in a period tends to get smaller"
 (Student 1, Interview, November 4, 2022)

Students do not understand the periodicity of the first ionization energy properties in one group and in one period.

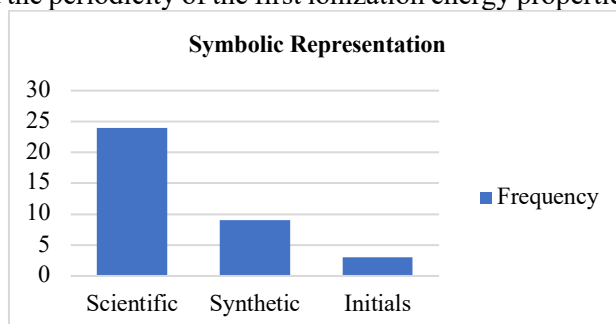


Figure 40. Histogram of Symbolic Representation of Ionization Energy

Konfigurasi elektron:
 a. 11Na = [Ne] 3s¹ ↑
 b. 19K = [Ar] 4s¹
 c. 37Rb = [Kr] 5s¹
 d. 55Cs = [Xe] 6s¹

Jadi berdasarkan konfigurasi unsur-unsur tersebut berada pada golongan yang sama yaitu golongan IA, dengan periode yang berurutan.
 Dengan demikian maka urutan unsur-unsur tersebut adalah dari atas ke bawah yaitu 11Na, 19K, 37Rb, 55Cs.
 Oleh karena itu unsur yang mempunyai energi ionisasi terbesar adalah 11Na.

Figure 41. Symbolic Representation of Scientific Categories

Students are correct in sequencing the periodicity of ionization energy from the smallest to the largest. Students write down the electron configuration of the element to determine the location of the element and then give the direction of the arrow up which shows that the element that has the lowest ionization energy is Cs and the element that has the highest ionization energy is Na. The elements Na, K, Rb, and Cs are elements located in one group, as has been written in the submicroscopic representation that the periodicity of ionization energy in one group from top to bottom will be smaller, so that the order of ionization energy from the smallest to the largest $Na > K > Rb > Cs$. This is in accordance with

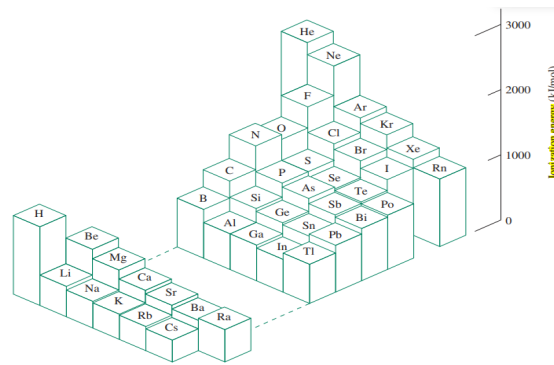


Figure 42. Periodicity of ionization energy in the periodic table

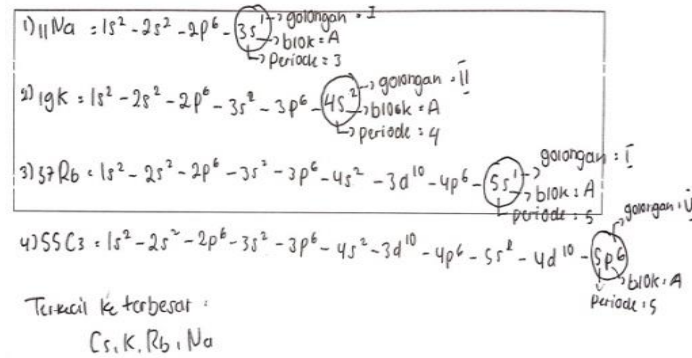


Figure 43. Symbolic representation of synthetic categories

Students are correct in sequencing the periodicity of ionization energy properties in one group but incorrectly determine the location of the group and period of the electron configuration that has been written.

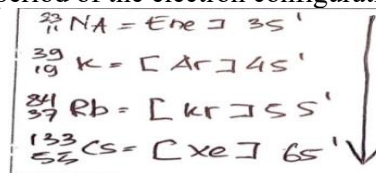


Figure 44. Symbolic representation of initial categories

Students are wrong in sequencing the periodicity of ionization energy from the smallest to the largest. Students write down the configuration of the element's electrons to determine the location of the element and then give the direction of the arrow down which shows that the element that has the lowest ionization energy is Na and the element that has the highest ionization energy is Cs. In addition, judging from the symbolic level, students are wrong in writing the symbols of the elements sodium, neon, krypton, and xenon. This shows that students do not understand the writing of elements in the periodic table of elements. The correct writing is in accordance with the rules of the *International Union of Pure and Applied Chemistry (IUPAC)*, namely Na, Ne, Kr, and Xe.

Mental Model on Electron Affinity Submatter

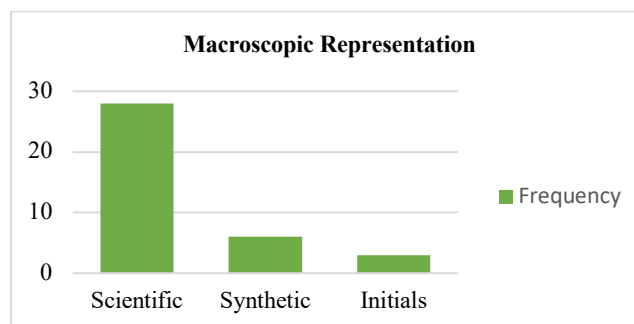
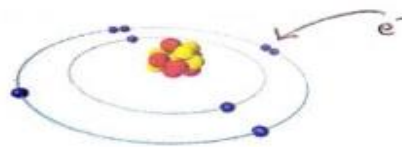


Figure 45. Histogram of Macroscopic Representation of Electron Affinity



Afinitas elektron adalah besarnya energi yang terjadi ketika atom netral yang berbentuk gas menerima satu elektron yang ditempatkan pada kulit terluar dan muatan atom menjadi negatif.

Figure 46. Macroscopic Representation of Scientific Category

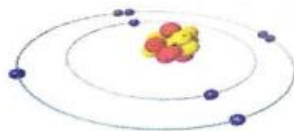
The first category of scientific mental models is reviewed from macroscopic representations, students are correct in representing what is meant by electron affinity, namely the amount of energy that occurs when a gaseous neutral atom receives an electron placed on the outermost shell and the atomic charge becomes negative. Students describe the incoming electron occupying the outermost shell of an oxygen atom. It is in accordance with Yang et al. (2024) that electron affinity is an energy change that occurs when one electron is received by an atom of an element in a gaseous state.



besarnya energi yang dihasilkan /dilepaskan apabila suatu atom menangkap elektron.

Figure 47. Macroscopic Representation of Synthetic Categories

The students answered incompletely, the change in energy that occurs when one electron is received by an atom of an element in a gaseous state.



Afinitas elektron adalah sebuah atom netral menerima sebuah energi dari jarak tak terhingga.

Figure 48. Macroscopic representation of Initial Category

Students are wrong in explaining the meaning of electron affinity and do not represent it, students think that electron affinity is a neutral atom that receives an energy from an infinite distance, electron affinity should be an energy change that occurs when an electron is received by an atom of an element in a gaseous state.

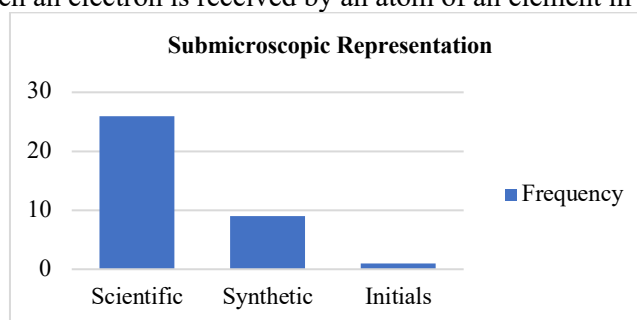


Figure 49. Histogram of Submicroscopic Representation of Electron Affinity

Dalam satu periode dari kiri ke kanan afinitas elektron suatu unsur cenderung semakin besar, karena pengaruh muatan inti yang semakin besar akibat elektron berada pada jarak yang semakin dekat dengan inti sehingga tarikan elektrostatik inti semakin besar. Jari-jari mengecil dan perubahan energi yang terjadi ketika elektron masuk ke dalam atom suatu unsur semakin besar.

Figure 50. Submicroscopic Representation of Scientific Categories

Students can correctly explain the periodicity of the affinity properties of electrons in a period. This is in accordance with Yang et al. (2024) that the first electron affinity trend in a period has increased electron affinity as the core charge increases. Furthermore, the synthetic category is reviewed from submicroscopic representations:

“..... In one group, the more shells, the smaller the electron affinity, while in a period, the fewer shells, the greater the electron affinity.”

(Student 8, Interview, November 4, 2022)

The students' answers are partly true and partly wrong, students assume that in one period the fewer shells there are so that the affinity of electrons is greater, the correct concept is that in one period the number of shells is the same. However, students have understood the tendency of electron affinity in one group and in one period.

Afinitas elektron dalam satu periode semakin kecil karena jari-jari atom semakin kecil.

Figure 51. Submicroscopic Representation of Initial Category

Students are wrong in explaining the periodicity of the affinity properties of electrons in a period. The atomic radius in one period tends to get smaller but the affinity value of electrons in one period tends to be larger.

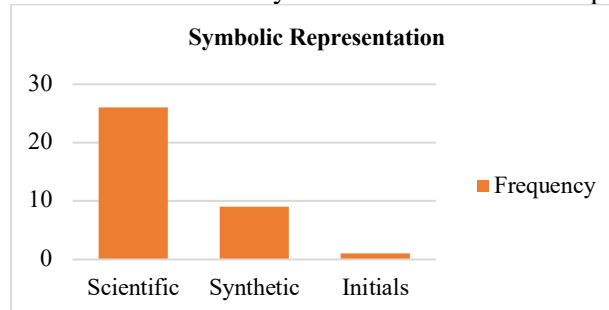


Figure 52. Histogram of Symbolic Representation of Electron Affinity

Yang lebih besar adalah afinitas elektron dari unsur Na (Natrium) dibandingkan unsur K (Kalium) karena jumlah kulit Na lebih sedikit dibandingkan K. Sehingga tarikan elektrostatik Na lebih kuat, perubahan energi yang terjadi ketika diterima oleh Na lebih besar dibandingkan K.

Figure 53. Symbolic Representation of Scientific Categories

Students can determine the element that has a greater electron affinity and give the reason for the correct answer. Na and K are elements located in one group because they have the same valence electrons, namely group IA. Referring to Yang et al. (2024) which states that the first trend of electron affinity in one group is a decrease in electron affinity, this is because in one group from top to bottom there is an increase in atomic size, the distance between the nucleus and the incoming electron increases and this results in a lower attraction so that the value of electron affinity will decrease, electron affinity $Na > K$.

Yang lebih besar adalah Na (Natrium)

Karena dalam satu golongan afinitas elektron, cenderung akan
berkurang jika dari atas ke bawah

Figure 54. Symbolic representation of synthetic categories

The student answered correctly but the explanation of the reason was incomplete. Students are only limited to knowing the tendency of electron affinity in one group to decrease from top to bottom. In addition, the synthetic category in the sub-material of electron affinity was also found from the results of interviews outside of learning hours with different questions but still in the same context, namely regarding the determination of the periodicity of electron affinity properties:

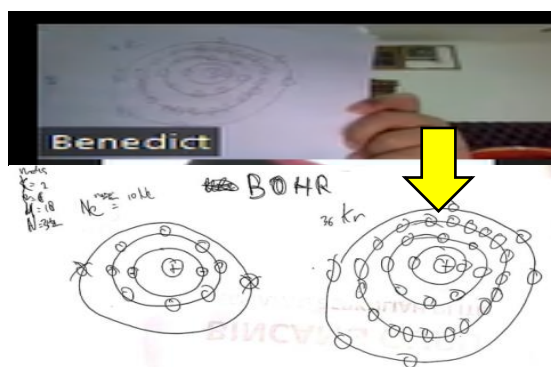


Figure 55. Students describe and explain orally their understanding of the periodicity of electron affinity

"The affinity of electrons is greater than Ne because from what I have drawn, the radius of the atom is smaller than Kr, the electron will surround the atom in a certain trajectory, the deeper the stronger, the greater the affinity of the electron, such as the solar system, the closer the stronger the attraction and the farther the attraction weakens, the farther the electron changes the energy that occurs when an electron is received by an atom of an element in a gaseous state, the smaller or affinity The electrons are getting weaker, right, if the earth is still in the earth, the earth experiences gravity, it's just that if it's from the place that is reached, the earth's gravity is the same, we don't follow the gravity of the earth, we float like that, the deeper it is, the smaller it is, as far as I know, the bigger the attraction."

(Student 8, Interview, November 21, 2022)

Students forget about one of the exceptions to the periodicity of the affinity nature of electrons of noble gas elements so that they are wrong in giving answers. However, the students' understanding of the periodicity of electron affinity properties seen from the explanation presented relates the periodicity of electron affinity to the periodicity of atomic radii and analogizes it with the earth's gravity is correct.

Siswa dilihat dari grafiknya lebih besar

Figure 56. Symbolic representation of initial categories

Students are unable to determine elements that have a greater electron affinity and do not provide reasons.

Mental Model on Electronegativity Sub-Material

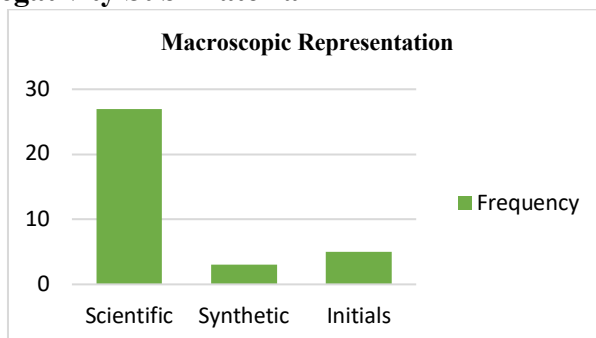


Figure 57. Histogram of Macroscopic Representation of Electronegativity

Keelektronegatifan adalah ukuran empiris mengenai kecenderungan atom untuk menarik elektron ikatan menuju dirinya sendiri

Figure 58. Macroscopic Representation of Scientific Category

Students can explain the concept of electronegativity correctly. This corresponds to (18) electronegativity is a measure of the relative ability of different atoms to attract bonding electrons towards itself.

"Electronegativity pulls electrons towards itself, I'm confused about electronegativity pulling or leaving"
(Student 17, Interview, November 21, 2022)

Students' answers lead to the correct concept, but students still have doubts about the answers they convey. This doubt occurs because students' understanding still likes to invert between ionization energy, electron affinity, and electronegativity, this is evidenced by the reflective journal:

"I understand this learning material but sometimes I still like to reverse the properties of ionization energy, electron affinity, and electronegativity"

(Student 17, Reflective Journal, November 11, 2022)

Apa yang kamu ketahui tentang keelektronegatifan?

Figure 63. Macroscopic representation of Initial Category

Students do not answer questions. This shows that students have a low ability to explain their knowledge of the concept of electronegativity.

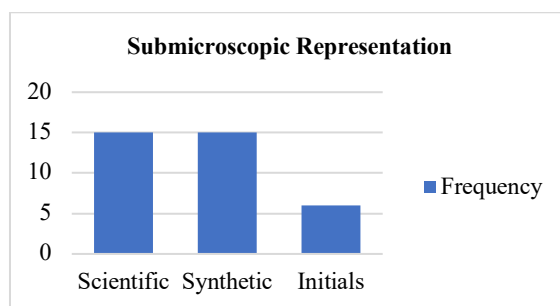


Figure 64. Histogram of Submicroscopic Representation of Electronegativity

Dalam satu golongan dari atas kebawah semakin turun karena dalam satu golongan efek perisai semakin besar, hal tersebut mengakibatkan jarak elektron ke inti semakin besar sehingga kemampuan atom untuk menarik pasangan elektron bersama semakin berkurang. Sedangkan, dalam satu periode dari kiri ke kanan semakin naik karena muatan inti semakin banyak sehingga mengakibatkan gaya tarik inti terhadap elektron semakin kuat.

Figure 65. Submicroscopic Representation of Scientific Categories

Students can answer and explain the periodicity of electronegativity properties correctly. This is in accordance with Yang et al. (2024) which states that the electronegativity of atoms generally increases from left to right across the periodic table, because the Z^* or charge of the nucleus effectively rises so that all valence electrons including electrons in bonds are attracted more strongly to the nucleus. Meanwhile, electronegativity generally decreases from top to bottom on the periodic table of elements because Z^* or the effective core charge often remains constant, so a small decrease in electronegativity is due to the larger size. The electrons bond farther away from the nucleus, and therefore slightly weaker attracted.

"In one period he goes left to right his electronegativity goes up, if he goes down in one group he decreases, the periodicity is in one group and in the same period as the affinity of electrons"

(Student 8, Interview, November 21, 2022)

Students only write down the periodicity of electronegativity in one group and in one period without explaining it.

Dalam satu golongan dari atas ke bawah keelektronegatifan semakin besar

Figure 66. Submicroscopic Representation of Initial Category

Students are wrong in determining the periodicity of electronegativity in one group.

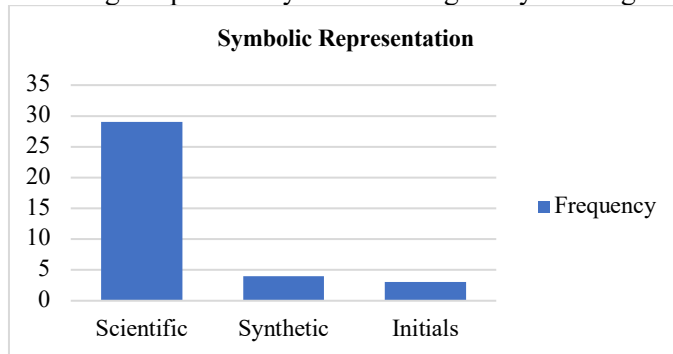


Figure 67. Histogram of Symbolic Representation of Electronegativity

Informasi yang didapatkan dari diagram di atas adalah bahwa elektronegativitas dari Na ke Cl semakin bertambah karena dalam satu periode Z^+ ~~naik~~ naik dimana elektron valensi akan lebih tertarik kuat ke inti sehingga elektronegativitas makin bertambah.

Figure 68. Symbolic Representation of Scientific Categories

Students can correctly answer the conclusions of information obtained from the data presented in the diagram regarding the electronegativity of the elements.

"Flour and Chlor fall into one group. If it goes down in one group, it means that he decreases his electronegativity, so the bigger the Flour."

(Student 8, Interview, November 11, 2022)

Students can correctly determine which elements have greater electronegativity but do not provide an explanation for the reason why the electronegativity F is greater than Cl.

Teacher: "Do nitrogen and chlorine have a difference in electronegativity?"

Student 17: "Yes, ma'am, Na and Cl have a difference in electronegativity, very different. The electronegativity is greater because nitrogen is closer to the nucleus of the atom when viewed from the Bohr atomic model."

(Student 17, Interview, November 21, 2022)

Students are wrong in comparing the difference in electronegativity of nitrogen and chlorine. Students consider nitrogen to have greater electronegativity than chlorine because it is closer to the nucleus. This is not in accordance with Yang et al. (2024) that the electronegativity of atoms generally increases from left to right across the periodic table, because the Z^+ or charge of the nucleus effectively rises so that all valence electrons including electrons in bonds are attracted more strongly to the nucleus.

Conclusion

Based on the results of the research that has been carried out, it was obtained that most of the students in class XB at SMAN 54 Jakarta have a scientific mental model. The scientific mental model is the highest because most students can write and describe both from the explanation of the development and components of the periodic table of elements, the periodicity of atomic radius, ionization energy, electron affinity and electronegativity to submicroscopic and symbolic representations, but there are still a small number of students who experience misunderstandings. During the learning process, students have been given 3D representations to make meaningful learning which is divided into three stages of the learning cycle learning model, namely: the engage stage, the explore stage, and the explain stage. In the engage stage, students are given LKPD to fill in during the learning hours which are guided by the teacher about developmental learning and components of the periodic table of elements, atomic radius, ionization energy, electron affinity, and electronegativity.

The mental model of the students as a whole obtained a percentage of 70.88% in the scientific mental model, 17.55% in the synthetic mental model, and 11.61% in the initial mental model. Students' mental models arise because

they are influenced by several factors, namely students' thoughts and experiences that they have beforehand, teachers' explanations, 3D representation learning media used during learning, handbooks or other sources. 3D representation learning media increases students' interest in learning chemistry because all students in class XB are new to the learning media. This 3D representation also helps students understand the learning material so as to improve the mental model of students.

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