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Overview of difficulties and material identification of chemical bonds based on multiple representations: Teacher's view

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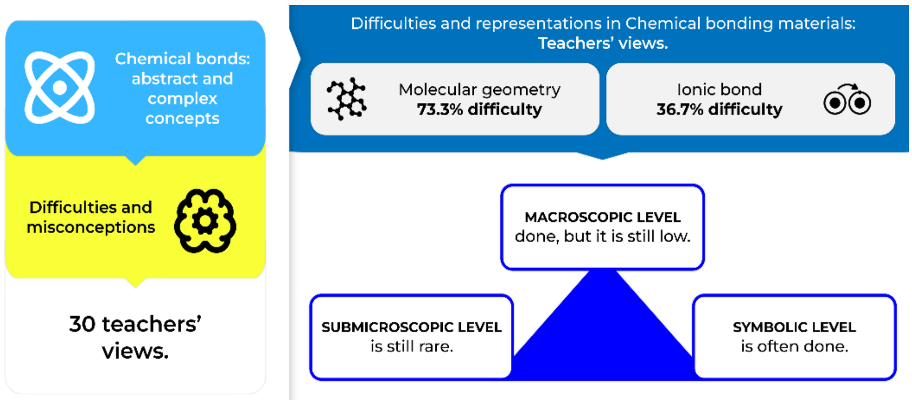
Abstract

Chemical bonding involves three levels of representation, namely macroscopic, submicroscopic, and symbolic, which are often difficult for students to understand due to their abstract and complex concepts. In this case, teachers play an important role as facilitators. However, teachers still experience various challenges in applying a multiple representation approach. This study aims to identify and analyze the difficulties in multi-representation-based chemical bonds based on the views of several chemistry teachers. A total of 14 open and closed question items via Google Forms were distributed online. Based on a survey of several chemistry teachers, the most difficult sub-material in chemical bonds is molecular geometry, while the easiest is ionic bonds. Chemistry teachers participating in this study tend to focus more on symbolic, macroscopic, and submicroscopic representations in teaching chemical bonds.



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1. chemical bonding representations;
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Highlights

- The method used was a survey method with 30 open and closed-question items.
- The molecular geometry sub-material is considered quite difficult for respondents.
- Explanations linking chemical bonding material with multiple representations are few.
- The findings are an identification of multi-representation-based chemical bonding.

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1. Introduction

Chemistry is a scientific discipline that focuses on studying the characteristics, structure, and changes in matter and energy (Widarti, 2021; Widarti *et al.*, 2025). Several concepts in chemistry create difficulties and different perceptions for students because abstract concepts dominate chemistry (Widarti *et al.*, 2018). In addition, there are several difficulties in learning chemistry based on its characteristics, namely: **a)** Chemistry simplifies the truth, resulting in a gap between understanding and applying concepts, **b)** Chemistry has a dynamic and rapidly evolving nature, making the materials studied in chemistry very complex, **c)** Chemistry can be applied in everyday life (Ahmar *et al.*, 2020).

Chemical bonds are one of the chemical materials studied in high school. Generally, chemical bonding is grouped into several sub-materials, including ionic bonds, covalent bonds, metal bonds, molecular geometry, and intermolecular forces (Dawati *et al.*, 2019). The concept of chemical bonding material is abstract and complex, so students have relative difficulty understanding the sub-subjects in chemical bonds (Widarti *et al.*, 2018). The research results of Sari *et al.* (2020). It shows that students have difficulty understanding the concept of chemical bonding. The percentages of each subconcept are as follows: stable electron configuration at 35.8%; valence electrons at 35.1%; ionic bonds at 55.4%; covalent bonds at 58.7%; and metal bonds at 54.3%. Yakina *et al.* (2017) also, show other research results on student learning difficulties in chemical bonding. The study shows that students had trouble in the term category of 48.99%, the 41.32% concept category, and the 70.97% calculation category. Based on this description, it can be concluded that students have not fully understood chemical bonding. Students' difficulties can stem from the threshold concept that students do not understand. If the concepts in chemistry are not well understood, students will experience learning difficulties, one of the impacts of which is the occurrence of conceptual errors or commonly called misconceptions (Meltafina *et al.*, 2019).

Misconceptions are one of the barriers to mastering concepts that need to be minimized (Hasanah *et al.*, 2024). Misconceptions are still a problem in the learning process because they can reduce the effectiveness of student learning and hinder students from mastering further concepts. If misconceptions are not addressed immediately, it will result in students' difficulties in understanding more complex concepts (Meltafina *et al.*, 2019). Based on the results of the research conducted by Setiawan and Ilahi (2022) that chemical bonding causes quite many misconceptions, namely the subconcepts of stability of electrons, the Lewis structure, duplet rules, octets and their exceptions, metallic bonds and metallic properties, VSEPR theory, van der Walls, ionic and covalent compounds. A deep understanding of chemical bonding is needed to minimize the percentage of misconceptions among students (Widarti *et al.*, 2018). Using appropriate chemical representations in the learning process can reduce students' misconceptions and help students understand chemical concepts as a whole (Hasanah *et al.*, 2024).

Chemistry deals with three levels of representation, namely the macroscopic level, which refers to what can be observed, the submicroscopic level, which relates to events at the molecular level, and the symbolic level, which refers to how the phenomenon is symbolized (Danin and Kamaludin, 2023; Widarti, 2021). Therefore, chemistry will be easier to understand if students can represent it in three levels of representation Hasanah *et al.*, 2024; Meltafina *et al.*, 2019; Siregar and Wiyarsi, 2023). In this case, teachers play an important role as facilitators to help students integrate the three levels of representation (Head *et al.*, 2017). The role of the teacher is vital in helping students see the relationship between these three levels so that students can form a deeper and more comprehensive understanding. However, teachers still experience various challenges in applying a multiple representation approach. Limited time and resources in the classroom, which often do not allow for an optimal variety of representations, are also a challenge for teachers (Li and Arshad, 2014).

Based on the background described the ability to use multiple representations must be developed in chemistry learning, especially chemical bonds. This study aims to analyze the difficulties and identify multiple representations of chemical bonds from the teacher's point of view. It is expected to provide insight into research needs and opportunities to assist chemistry teachers in overcoming difficulties and identifying chemical materials.

2. Experimental

This research uses a survey method. The research instrument contains 14 items of open and closed questions about learning chemical bonding material in schools conducted by chemistry teachers. The instrument that has been developed is then disseminated online through Google Forms. The survey instrument grid used is presented in **Table 1**.

Table 1. Survey instrument grid.

Main component	Indicator	Number and Type of Questions
Chemical bonding material	Easy and difficult chapters	– 3 closed questions with a scaled answer – 2 closed questions with more than 1 answer choice
Multiple representation approach	The use of representation in learning	– 4 closed questions with a scaled answer – 1 closed question with more than 1 answer choice
	Media and learning resources that support the multiple representation approach	– 3 closed questions with a scaled answer – 1 closed question with more than 1 answer choice
Total		**14 Questions**

Source: Elaborated by the authors.

Respondents who filled out the survey were 30 chemistry teachers. The data obtained were analyzed using quantitative data analysis techniques. Quantitative data was obtained from the results of questionnaires distributed to respondents. The data that has been collected is then analyzed in several stages. First, the data collected from respondents was downloaded in spreadsheet format to facilitate further processing and analysis. Next, the data was analyzed using descriptive statistics to get an overview, such as the percentage and average of each answer. For quantitative questions, percentages were used to understand respondents' tendency patterns. The results of each analysis are displayed in graphs and tables to facilitate interpretation and draw conclusions relevant to the research objectives. The teacher demographic data is shown in **Table 2**.

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Table 2. Teacher demographic data.

Demographics	Amount		%
Gender	Male	10	33.3
	Female	20	66.7
School Location	Java	29	96.7
	Outside Java	1	3.3

Source: Elaborated by the authors.

3. Results and Discussion

3.1. Difficulty in chemical bonding material

Students' difficulties in learning chemistry are in line with the characteristics of chemistry itself, including that most of chemistry is abstract, sequential and rapidly developing, chemistry is a simplification of the actual material, and the material studied is very complex (Halim *et al.*, 2013; Mindayula and Sutrisno, 2021; Siregar and Wiyarsi, 2023; Widarti, 2021). In studying chemistry, students need to have several abilities, including the ability to think formally, memorize, perform mathematical operations, and have spatial intelligence (Rahmawati *et al.*, 2021).

Several students expressed their difficulties in learning chemistry, including the influence of the teacher, materials, media, and learning methods applied by the teacher. In addition, students' challenges in chemistry learning are due to the abstract nature of chemical concepts, which teachers also recognize (Halim *et al.*, 2013; Hasanah *et al.*, 2024; Widarti *et al.*, 2018). This is in line with the results of a survey conducted by researchers, which found that 56.7% of chemistry teachers stated that chemical bonding material was tricky. The researcher also surveyed the level of difficulties experienced by chemistry teachers in several sub-materials of chemical bonds, namely ionic bonds, covalent bonds, metal bonds, physical properties of chemical bonds, molecular geometry, and intermolecular forces. The survey data on the chemistry teacher's difficulty level with the sub-materials of the chemical bonds is shown in Fig. 1 and 2.

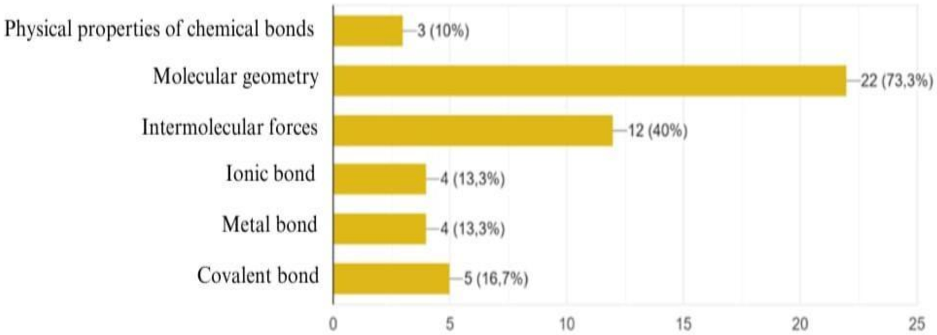

Figure 1. The most difficult sub-material of chemical bonds according to chemistry teachers.
Source: Elaborated by the authors.

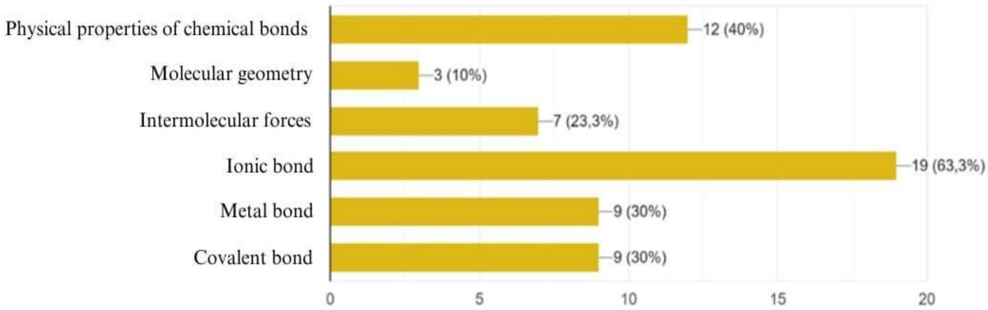

Figure 2. The easiest sub-material of chemical bonds, according to chemistry teachers.
Source: Elaborated by the authors.

Based on Fig. 1, as many as 73.3% of chemistry teachers consider molecular geometry the most difficult sub-material concerning chemical bonds. Molecular geometry is an essential sub-material in chemical bonds because it has a role in determining the physical and chemical properties of the molecule (Nugraha *et al.*, 2019). Molecular geometry is a challenging topic in terms of conceptual understanding and teaching. The relevance of this data can also reflect the challenges chemistry teachers face in delivering this material to students. In the molecular geometry sub-material, if students only understand through Lewis structure, they will have difficulty distinguishing the shapes of molecules in a compound. For example, the compounds CO_2, SO_2, and H_2O have identical bond pairs but have different molecular shapes. If students are only shown the Lewis structure, they may assume that the three compounds have the same shape. This is in line with the research of Siregar and Wiyarsi (2023), which states that teaching abstract concepts such as molecular geometry requires representational skills, including the ability to visualize things that cannot be seen directly and to create 3D visualizations of molecular geometry.

Molecular geometry is considered difficult by chemistry teachers because the material is more complex in linking other sub-subjects (Nugraha *et al.*, 2019; Siregar and Wiyarsi, 2023). In addition, chemistry teachers often experience difficulties when teaching molecular geometry due to the limitations of media to explain the shape of molecules in 3D versions, so students will have trouble imagining the shape of molecules if they are only depicted in 2D form on a whiteboard or image in PowerPoint. This will have an impact on students' understanding to understand the sub-material of molecular geometry. Some students do not understand the Lewis structure and valence electrons, so it is

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difficult to imagine the shape of a molecule. Then, the molecular geometry material requires imagination, which must be expressed visually, but the learning media used by the teacher are inadequate.

The difficulty of the molecular geometry sub-material can be observed, for example, when determining the molecular geometry of PF_5. The first thing to do is identify the number of valence electrons of each atom involved. In PF_5, there are 5 valence electrons from the P atom and 7 valence electrons from each F atom, so the total number of valence electrons is 40. Then, the central atom is determined by looking at the more electropositive atom than the F atom; the P atom becomes the central atom. **Figure 3** shows the Lewis structure of PF_5.

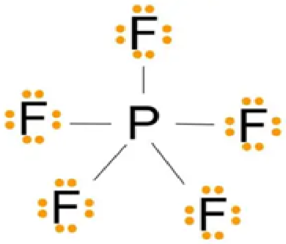

Figure 3. Lewis structure of PF_5.
Source: Elaborated by the authors.

From the Lewis structure of PF_5 above, it can be observed that all the valence electrons of the P atom are paired in the F atom so that there are no lone pairs of electrons in the P atom. Three Fluorine atoms are in the equatorial position, while the other two are in the axial position (Effendy, 2017). This arrangement of atoms forms the trigonal bipyramidal geometry of the PF5 molecule. Thus, in determining the molecular geometry of PF5, it is necessary to understand interrelated concepts such as valence electrons and Lewis structure, so molecular geometry becomes a difficult sub-subject matter.

Meanwhile, when reviewed based on **Fig. 2**, which is the result of a survey of the level of ease of chemistry teachers in teaching sub-material on the topic of chemical bonds, it is known that the most significant percentage, namely 63.3% of chemistry teachers stated that the ionic bonding sub-material is easier to teach to students than other sub-materials. This can be based on the concept of ionic bonds, which is quite simple compared to other sub-matter. Ionic bonds can be easily explained to students by looking at and distinguishing the constituent elements that are bonded to each other, and students can also easily determine which ion is charged.

Ionic bonds, if taught to students, will be easier to understand because examples of compounds and material cores of ionic sub-bonds can be reviewed directly by students in daily life, such as table salt (NaCl). In the NaCl compound, the Na atom has 1 valence electron, so it tends to give up electrons while the Cl atom has 7 valence electrons so it tends to accept 1 electron to fulfill the octet rule (Effendy, 2020). **Figure 4** shows the Lewis structure of NaCl.

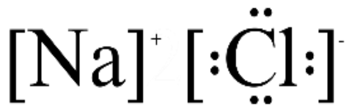

Figure 4. Lewis structure NaCl.
Source: Elaborated by the authors.

3.2. Identification of chemical bonds based on multiple representations

The multiple representation approach in chemistry learning utilizes various forms of representation to help students understand abstract chemical concepts (Danin and Kamaludin, 2023; Hasanah *et al.*, 2024; Widarti, 2023). A comprehensive understanding of chemistry is directly linked to the comprehension of macroscopic, submicroscopic, and symbolic representations, as well as the relationships between these three forms (Widarti, 2021). Multiple representations are needed in every chemical material, especially in chemical bonds.

3.2.1. Macroscopic level

Macroscopic is a chemical representation that looks real using the sense of sight (Widarti, 2021). **Figure 5** shows the frequency of chemistry teachers' explanations at the macroscopic level, where the order of the Likert scale answers is: (1) never, (2) occasionally, (3) sometimes, (4) often, and (5) always. Based on **Fig. 5**, the data shows that most chemistry teachers are neutral with a slightly more positive response (46.7% choosing scales 4 and 5), and only a small proportion (3.3% on scale 2). This shows that most chemistry teachers have used macroscopic representations in teaching chemical bonding material. For example, is the change in table salt (NaCl) when heated or cooled? This is because table salt (NaCl) is a standard material that is easily found daily. In addition, NaCl has physical properties that are easily observed at the macroscopic level, such as solubility in water and a high melting point. Teachers can easily demonstrate these properties through simple experiments, such as dissolving salt in water. This is in line with the research of Hasanah *et al.* (2024), which states that chemistry teachers usually use NaCl as an example for macroscopic representation. This is because general chemistry books often use experimental images of reactions forming NaCl ionic compounds to illustrate phenomena that occur at the macroscopic level.

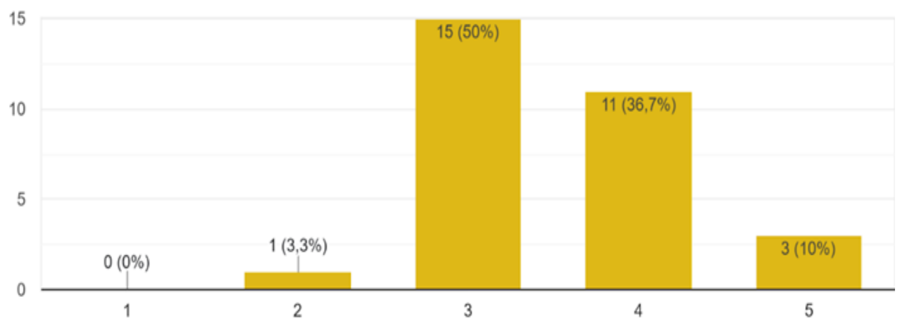

Figure 5. Frequency of chemistry teachers' explanations at the macroscopic level.
Source: Elaborated by the authors.

3.2.2. Submicroscopic level

Submicroscopic are descriptions of phenomena that can't be seen with the naked eye or even with a microscope, such as atoms, ions, and molecules. The submicroscopic level is a level that describes the structure of chemical substances and their phenomena, reaction mechanisms that occur, atomic or molecular interactions, and chemical changes that underlie a phenomenon (Widarti, 2021). **Figure 6** shows the frequency of chemistry teachers' explanations at the submicroscopic level, where the order of the Likert scale answers is: (1) never, (2) occasionally, (3) sometimes, (4) often, and (5) always. Based on **Fig. 6**, the data shows that most chemistry teachers are neutral, with a slightly more positive response (26.7% choosing scales 4 and 5), and only a small proportion never (10% on scale 2). This is due to the submicroscopic level, which involves understanding particles such as atoms, ions, and electrons that cannot be seen directly, making it an abstract concept for students. For example, chemistry teachers stated that students have difficulty understanding the concept of molecular geometry without in-depth visualization, so students will find it difficult when learning the theory more realistically.

The limitations of learning media, such as animations or 3D models, are also a factor. Some general chemistry books often do not provide submicroscopic representations for molecular geometry concepts (Hasanah *et al.*, 2024). Chemistry teachers often focus more on macroscopic and symbolic representations because they are easier to explain and more relevant in the context of laboratory experiments or everyday learning (Mindayula and Sutrisno, 2021; Siregar and Wiyarsi, 2023). Submicroscopic processes are considered an extension of this basic understanding. Widarti (2021) stated that chemistry teachers rarely use learning media that can help students understand concepts through submicroscopic representations. However, submicroscopic representations play a crucial role in illustrating the nature of material particles such as atoms, ions, and molecules, which cannot be observed directly and are the basis for interpreting chemical concepts or phenomena.

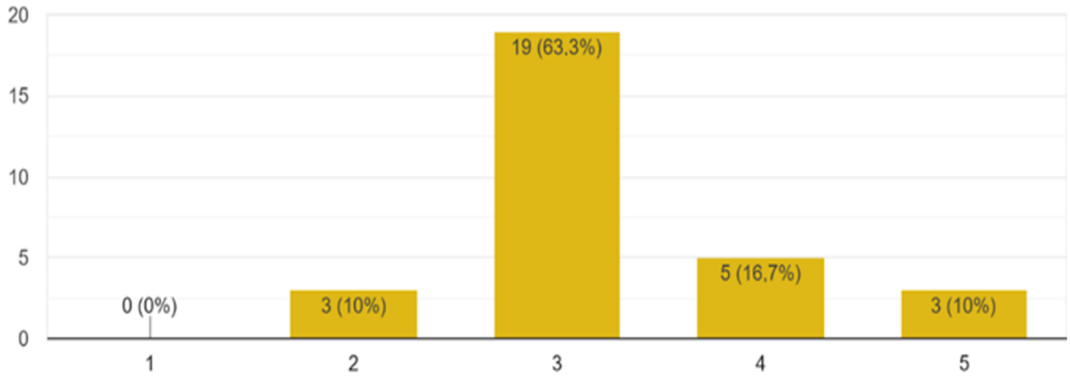

Figure 6. Frequency of chemistry teachers' explanations at the submicroscopic level.
Source: Elaborated by the authors.

3.2.3. Symbolic level

Symbols in chemistry can be pictures, reaction equations, chemical formulas, diagrams, stoichiometry, and mathematical calculations. In addition, symbols in chemistry also show the form of a substance and the number of atoms in an ion or molecule (Widarti, 2021). **Figure 7** shows the frequency of chemistry teachers' explanations at the symbolic level, where the order of the Likert scale answers is: (1) never, (2) occasionally, (3) sometimes, (4) often, and (5) always. Based on **Fig. 7**, most chemistry teachers gave neutral to positive responses (66.6% choosing scales 4 and 5). This shows that most chemistry teachers have used symbolic representations in teaching chemical bonding material. For example, there are the concepts of writing the electron configuration of an element and the concept of describing the Lewis structure of a compound. Both concepts use symbols to present complex and abstract information in a more straightforward and easily understandable form. This is in line with the research of Hasanah *et al.* (2024), which states that concept of describing Lewis structures using symbolic representation.

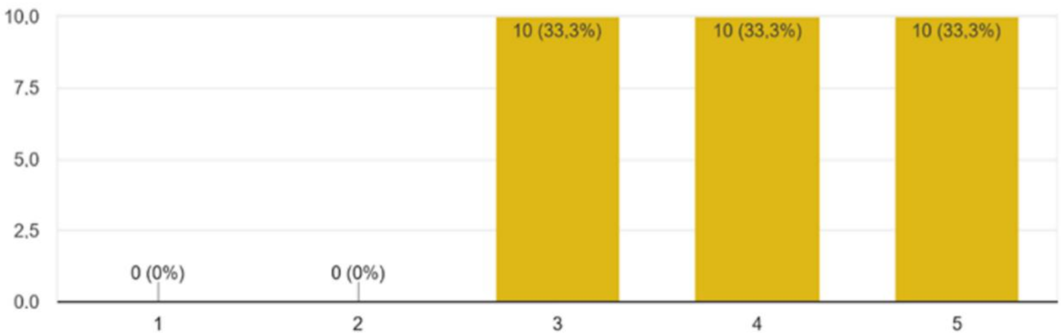

Figure 7. Frequency of chemistry teachers' explanations at the symbolic level.
Source: Elaborated by the authors.

4. Conclusions

Based on the results of the discussion above, it was found that chemistry teachers find molecular geometry the most difficult sub-material of chemical bonds and ionic bonds the easiest. Chemistry teachers participating in this study tend to focus more on symbolic, macroscopic, and submicroscopic representations in teaching chemical bonds. This study recommends developing learning media for chemical bonds that integrate the three types of representations to facilitate understanding of abstract concepts.

Authors' contribution

Conceptualization: Hayuni Retno Widarti; Antuni Wiyarsi; Sri Yamtinah; Ari Syahidul Shidiq; **Data curation:** Meyga Evi Ferama Sari; Putri Nanda Fauziah; Shella Natasya; Cahya Aulia Khandi; Deni Ainur Rokhim; **Formal analysis:** Ari Syahidul Shidiq; Cahya Aulia Khandi; Deni Ainur Rokhim; **Funding acquisition:** Hayuni Retno Widarti; **Investigation:** Meyga Evi Ferama Sari; Putri Nanda Fauziah; Shella Natasya; Cahya Aulia Khandi; Deni Ainur Rokhim; **Methodology:** Hayuni Retno Widarti; Antuni Wiyarsi; Sri Yamtinah; **Project administration:** Hayuni Retno Widarti; **Resources:** Not applicable; **Software:** Deni Ainur Rokhim; **Supervision:** Antuni Wiyarsi; Sri Yamtinah; **Validation:** Hayuni Retno Widarti; Ari Syahidul Shidiq; **Visualization:** Shella Natasya; Putri Nanda Fauziah; **Writing – original draft:** Putri Nanda Fauziah; Shella Natasya; **Writing – review & editing:** Hayuni Retno Widarti; Antuni Wiyarsi; Sri Yamtinah.

Data availability statement

All data sets were generated or analyzed in the current study.

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Conflict of interest

The authors declare that there is no conflict of interest.

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