

Analysis of high school students' mental model on bacteria concept: representation of students' conceptions

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Abstract

Keywords:

Bacteria;
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Concept Map;
Drawing-Writing;
Test;

Mental model is an internal representation formed by individuals in explaining a concept. Previous research on mental models of bacteria concept has been carried out on university students, but has not been carried out on high school students. The purpose of this study was to analyze the mental model of high school students about bacteria using drawing-writing tests and concept map. This study uses a descriptive method with 30 students of class X in one high school in Bandung as respondents. Students' answers are then compared with the expert's mental model as the targeted mental model. Students' mental models through the drawing-writing test are categorized into five levels (levels 1-5), namely no pictures/writing, pictures/writings are wrong or irrelevant, pictures/writings are partially correct, pictures/writings have some errors, pictures/writings correct and complete. Students' mental models through concept maps are categorized into four levels (levels 1-4), namely emergent, transitional, close to extended, extended. The results showed that it was easier for students to represent the structure and reproduction of bacteria through pictures than writing. The students' mental models through drawing (D) and writing (W) were highest at levels D5 and W5 for the concept of bacteria structure and reproduction. The most dominant mental model level is D4/W2 for the concept of bacteria structure and reproduction. The lowest students' mental model is D2/W2 for the concept of bacterial structure and D1/W1 for the concept of bacterial reproduction. Students' mental models through concept maps show that the highest level is level 3 (close to extended). The most dominant and lowest level of mental model is level 1 (emergent). The conclusion of this study shows that the mental model of students on bacteria was still not close to the mental model of experts.

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Introduction

In the 21st century, the world is growing with all the progress that exists. This change causes a person to have 21st century skills to prepare for a better life and be ready to face challenges in the future. One way to develop 21st century skills is through education. Someone does not have these skills from birth, but these skills are obtained through a process of practice, learning, or experience (Rhedana, 2019; Partnership for 21st Century Skills, 2019). So, it is important for students to know the concepts in science lessons, including biology. To find out the conception of knowledge that exists in a person can be known by analyzing mental models (Jalmo & Suwandi, 2018; Hamdiyati et al., 2018a; Varela et al., 2018; Jee et al., 2015).

Learning contains two main characteristics, namely: (1) maximally involving students' mental processes that require activities to think and (2) learning is directed at improving and enhancing students' thinking abilities in obtaining knowledge that they construct themselves through cognitive work (Wijaya et al., 2016). Ausubel (in Dahar, 2011) explained that learning can be classified into two dimensions. The first dimension relates to the way information or subject matter is conveyed to students through acceptance or discovery. The second dimension concerns the way in which students can relate the information to existing cognitive structures, which is called meaningful learning. Cognitive structures are facts, concepts, and generalizations that have been learned and remembered by students (Dahar, 2011). Achieving meaningful learning begins with constructing correct mental models, or representations of acquired knowledge (Michael, 2004). Knowledge, students' conceptions and interconnections between concepts can be fully detected by exploring their mental models (Hamdiyati et al., 2017).

Mental models can provide an indication of what students understand about a particular concept and include their knowledge and beliefs about the concept (Bryne, 2011). Mental models combine diverse knowledge from various sources. Direct experience with phenomena, through teaching, learning, and informal educational experiences, can all contribute to the formation of mental models (Buckley and Boulter, 2000). To measure students' mental models, several techniques can be used, including drawing-writing tests and concept maps. Drawing test is one of the instruments used to see how students' mental models are. Through pictures students can express the extent of understanding and knowledge of important concepts that students have, determine what students have learned (McNeil, 2014). Pictures as an organizing tool and a tool to express students' thoughts about related concepts. So that teachers can assess the extent to which students' understanding levels (Edens and Potter, 2007). Writing can be used as an instrument to analyze students' mental models. The language used is the key to understanding mental models, because language is a representation of students' mental models. Through language, teachers can see the extent of information and knowledge possessed by students through texts or writings made by students (Carley and Palmquist, 2014). Concept map is flexible tools that can be used to describe students' existing understanding (Kinchin et al., 2000). The concept map network can be a well-expressed map for interpreting their mental models (Chang 2007). Mental models for early and late nursing students use concept maps, indicating that final year student concept maps more closely resemble expert mental models compared to entry level students (Drach-Zahavy et al., 2017)

Previous research on mental models has been carried out on students on bacteria concept. From research conducted by Hamdiyati et al. (2018a) shows that the mental models that students have as prospective teachers vary widely. The most dominant is at the D2/W2 level. However, research on mental models, especially on bacteria concept, has not been carried out to high school students and bacteria concept is one of the concepts that high school students find difficult. The purpose of this study was to obtain an overview of the mental model of high school students on the Bacteria concept. By knowing students' mental models, it can be information for teachers to use appropriate learning methods, especially on bacteria concept, so that students understand this material better and become meaningful learning. The specific purpose of this research is to get a picture of the mental model of high school students on bacteria concept through drawing-writing and concept maps.

Method

Research Design

This research is descriptive research. The researcher will give 4 questions related to the structure and reproduction of bacteria for the drawing-writing test and one question to make a concept map of bacteria. Questions are given through Google Classroom. Students' answers that have been collected will be assessed and the mental model level category will be determined. Then the students' answers will be compared with the mental model of the expert.

Instrument

The research instrument used to measure students' mental models was to use a drawing-writing test and concept maps (Hamdiyati et al., 2018a, Hamdiyati et al., 2018b, Hamdiyati et al., 2018c).

Procedure

The research begins by compiling a research proposal, then making research instruments and rubrics. Quantitative data was collected using drawing-writing techniques and concept maps. The drawing-writing test instrument consists of four essay questions, two of which are instructions for drawing and explaining the structure of bacteria, while the other two are related to the reproduction of bacteria. Students' answers were analyzed and graded to describe students' mental models.

Data Analysis Techniques

The data were analyzed using the drawing-writing rubric and the concept map rubric, then the levels of mental model achieved by students will be obtained and will be compared with the mental model of the expert. The mental model level of students describes how students' mental models describe the structure and reproduction of bacteria. In the drawing-writing test, students' answers are classified according to a rubric adapted from Hamdiyati et al. (2018a). The rubric for the assessment of drawing-writing techniques is in Table 1.

Table 1. Category of Students' Mental Model Level through Drawing-Writing Test

Level	Statements	Drawing	Writing
Level 1	No pictures/text	D1	W1
Level 2	Image/writing is wrong or irrelevant	D2	W2
Level 3	Image/writing is partially correct	D3	W3
Level 4	There are some mistakes in the picture/writing	D4	W4
Level 5	Image/writing is correct and complete	D5	W5

The concept map of each student will be compared with a reference concept map, which is a concept map made by researchers that has been validated by expert lecturers in the field of Microbiology. The student's score will be converted into percent to further determine the level of mental model achieved by the student. The rubric for assessing the respondent's concept map refers to Table 2.

Table 2. Category Levels of Students' Mental Models through Concept Maps

Level	Categories	Description
1	Emergent	Less than 25% of important concepts are raised, relationships between concepts are illustrated completely and correctly with proper links, hierarchies, and cross links are also appropriate.
2	Transitional	Only 25-50% of important concepts are raised, the relationship between concepts is illustrated completely and correctly with appropriate conjunctions, hierarchies, and cross links are also appropriate.
3	Close to extended	Only 51-75% of the important concepts are raised, the relationship between concepts is illustrated completely and correctly with the right conjunctions, hierarchies, and cross links are also appropriate
4	Extended	More than 75% of the important concepts raised, the relationship between concepts is illustrated completely and correctly with appropriate conjunctions, hierarchies, and cross links are also appropriate.

(Hamdiyati et al., 2018b)

Results and Discussion

In this study, students' mental models were analyzed from students' answers through drawing-writing tests, especially on the concept of the structure and reproduction of bacteria and through concept maps. Questionnaires were given to all students to obtain supporting information from students' answers. Then interviews were conducted with several students to strengthen the students' answers and related data from the drawing-writing tests and concept maps. The results of the analysis of students' mental models about the structure and reproduction of bacteria through drawing-writing tests and concept maps are presented in Table 3, Table 4, Table 5, Table 6, and Figure 1, Figure 2, Figure 3, and Figure 4.

Table 3. Frequency Distribution of Students' Mental Models through Drawing-Writing Test

Concept	Level	W1	W2	W3	W4	W5	Total
Bacteria Structure	D1	-	-	-	-	-	0
	D2	-	2	-	-	-	2
	D3	-	5	-	-	-	5
	D4	-	18	1	1	2	22
	D5	-	1	-	-	-	1
	Total	0	26	1	1	2	30
Bacteria Reproduction	D1	1	-	-	-	-	1
	D2	-	3	-	-	-	3
	D3	-	-	-	-	-	0
	D4	-	8	-	-	3	11
	D5	-	7	-	1	7	15
	Total	1	18	-	1	10	30

Based on Table 3. the level of the most dominant mental model through the drawing-writing test is at levels D4 and W2 for the concept of structure and the concept of bacterial reproduction. Students can reach the highest level of D5 and W5 level on the concept of bacterial structure and reproduction, but the number who reach the D5 and W5 level on bacterial structure is less than on the concept of bacterial reproduction. The lowest level for the concept of bacterial structure is at levels D2 and W2, while for the concept of bacteria reproduction it is at levels D1 and W1. Then, when viewed from the total frequency of mental models at levels 4 and 5, it is known that students tend to be better at representing the concept of the structure and reproduction of bacteria through drawing test than writing test.

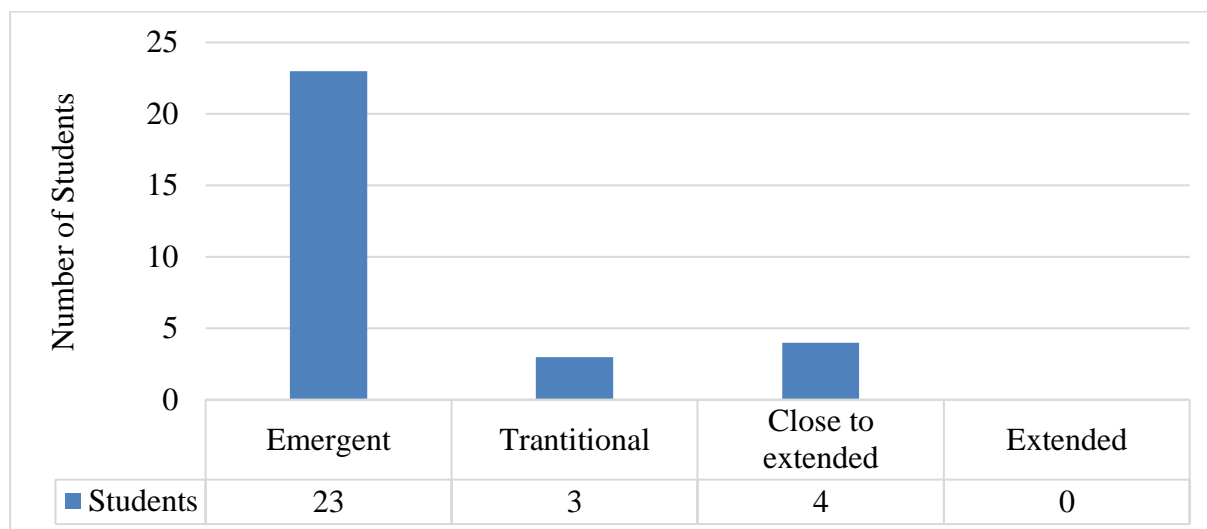


Figure 1. Students' Mental Models through Concept Maps

From Figure 1 it is found that the level of students' mental models through concept maps is the most dominant and also the lowest is level 1 (emergent), the highest level is at level 3 (close to extend) and no student has reached level 4 (extended). Study conducted by Albaiti et al. (2022) stated that high school students' mental models' tests showed that most high-cluster students were able to think abstractly, especially in giving explanations at the sub microscopic level when compared to medium-and low-clusters students. The mental model of students through concept maps is more dominant at level 1 (emergent) which has not yet approached the mental model of an expert. According to Hamdiyati et al. (2022a) the mental model of students on virus was still not close to the mental model of experts. The results of the fungi mental model research also show that the results are not yet close to the expert mental model (Hamdiyati et al., 2022a).

Table 4 is an example of students' mental models about the structure of bacteria through drawing tests at levels 2,3,4 and 5. Figure (2) level D2 is an irrelevant image of the structure of bacteria. Students draw the structure of bacteria with different shapes, which are not in accordance with the actual picture of bacteria, nor are there any descriptions of the structural components of the bacteria. Figure (2) level D3 is a picture of the structure of bacteria partially correct, more incorrect answers than correct answers. Students can only describe with descriptions of 1-4 cell components, while other components are not listed or are inaccurate. Figure (3) level D4 is a picture of the structure of bacteria that contains several errors, more

correct answers than wrong answers. Students draw with descriptions of 5-8 cell components. Figure (4) level D5 is a picture of the structure of bacteria correctly and precisely. Students can draw and include all the descriptions of cell components correctly.

Table 4. Examples of Students' Mental Models on Bacterial Structures through Drawing Tests

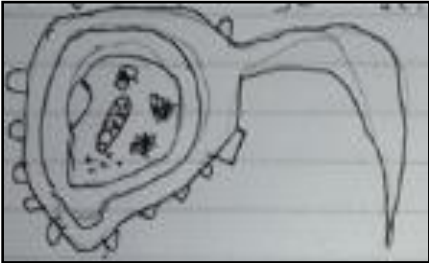
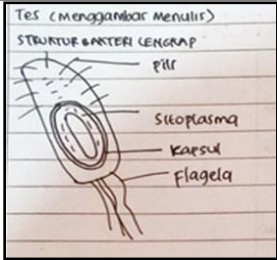
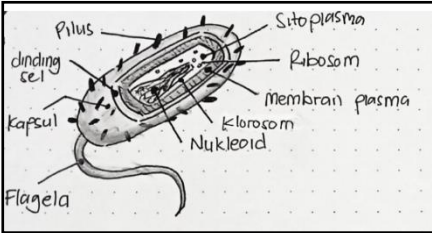
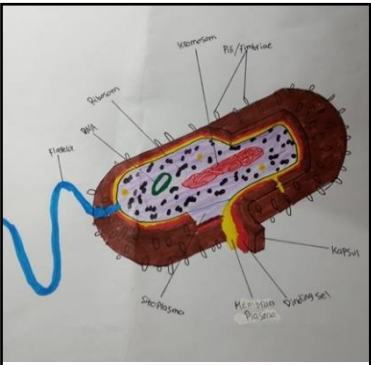
No	Example of Student Mental Model	Level
1		D2 (Image/writing is wrong or irrelevant)
2		D3 (Image/writing is partially correct)
3		D4 (There are some mistakes in the picture/writing)
4		D5 (Image/writing is correct and complete)

Table 5. is an example of a student's mental model of bacterial reproduction through drawing tests at levels 2, 4 and 5. Figure (1) level D2 is a reproduction image that is less relevant to the actual reproduction of bacteria, where students only draw two oval shapes without showing them. part of the bacteria. Figure (2) level D4 is a partially correct reproduction of the bacteria. Students only draw 3 of the 4 stages that should be described. Figure (3) level D5 is a true and correct image. Students can draw 4 stages of reproduction correctly and precisely.

Table 5. Examples of Students' Mental Models on Bacterial Reproduction through Drawing Tests

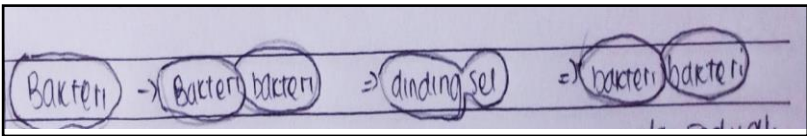

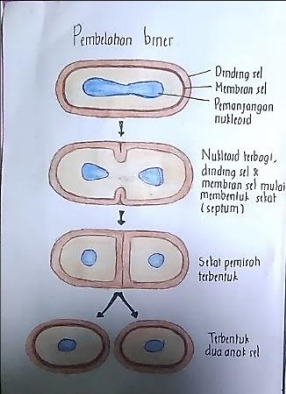
No	Example of Student Mental Model	Level
1		D2 (No pictures/text)
2		D4 (There are some mistakes in the picture/writing)
3		D5 (Image/writing is correct and complete)

Table 6. shows examples of students' mental models about the concept of bacterial structure and reproduction through a writing test. Level W2 is a student's answer that is wrong or irrelevant, on the concept of bacterial structure students only mention cell components but do not explain them. Then some students answered by explaining the function and not explaining the structure of bacterial cells. In the concept of bacterial reproduction, students only explain the definition of bacterial reproduction, not explain the stages of bacterial reproduction. Level W3 on the concept of bacterial structure is the student's answer which only explains 1-4 cell components correctly. The concept of bacterial reproduction only explains 1-2 stages of bacterial reproduction. Level W4 on the concept of bacterial structure is the student's answer that explains 5-8 cell components correctly. On the concept of bacterial reproduction, the student's answer explains 3 of the 4 stages of bacterial reproduction correctly. Level W5 on the concept of bacterial structure is the student's answer that explains all cell components correctly. In the concept of bacterial reproduction, the student's answer explains the 4 stages of bacterial reproduction correctly.

Table 6. Examples of Students' Mental Models Through Writing Tests

Concept	Example of Student Mental Model
Bacteria Structure	<p>The structure of bacteria has two structures, namely the inner and outer structures.</p> <p>The outer structure consists of:</p> <ul style="list-style-type: none"> ▪ Cell wall ▪ Capsules ▪ Cell membrane ▪ Flagella ▪ Pili <p>The inner structure consists of:</p> <ul style="list-style-type: none"> ▪ Cytoplasm ▪ Nucleoids ▪ Ribosomes ▪ Plasmid
	<p>(W2)</p> <ul style="list-style-type: none"> ▪ Pili help adhere to substrate ▪ Protective cell walls and maintain shape ▪ Capsules as a protective layer, preventing cell dryness ▪ Plasma membrane for transporting nutrients and regulating substances into and out of bacteria ▪ Cytoplasm as a place for cell metabolic reactions ▪ Ribosomes where protein synthesis occurs ▪ DNA as a regulator of cell activity ▪ Flagella as a means of movement of bacteria
	<p>(W2)</p> <ul style="list-style-type: none"> ▪ The cell wall is made of peptidoglycan which is a polysaccharide ▪ Pili are fine hairs that grow from the cell wall. Similar to flagella but shorter and stiffer ▪ Flagellum is a locomotor shaped like a whip
	<p>(W3)</p> <ul style="list-style-type: none"> ▪ Capsules, bacterial cells can produce mucus to the surface of the cells. The mucus is composed of water and polysaccharides ▪ The cell wall in bacteria is made up of peptidoglycan ▪ Plasma membrane composed of phospholipids and proteins ▪ Pili are fine hairs that grow from the cell wall ▪ Flagella are also referred to as whip feathers that are found on the cell wall ▪ Cytoplasm is a colorless liquid composed of air, organic matter, enzymes, mineral salts and nucleic acids ▪ The nucleoid is a pseudo nucleus where bacterial DNA is gathered
<p>(W4)</p> <ul style="list-style-type: none"> ▪ Cell wall contains peptidoglycan ▪ Plasma membrane contains phospholipids and proteins ▪ Ribosomes contain protein and RNA ▪ Capsules contain glycoprotein ▪ Flagella contain protein ▪ Cytoplasm contains mineral salts, enzymes, DNA, ribosomes, proteins, fats, carbohydrates ▪ Genetic chromosomes contain genetic material 	

Concept	Example of Student Mental Model
Bacteria Reproduction	<ul style="list-style-type: none"> • Pili contain compound protein • The nucleoid contains prokaryotic chromosomal DNA (W5)
	Bacteria undergo asexual reproduction by means of binary fission, namely the division of one cell, into two cells and so on. This binary fission includes amitotic division, meaning that the division does not involve the stages of cell division like humans, but takes place spontaneously or directly. (W2)
	The stages of binary fission are: <ul style="list-style-type: none"> • Cytoplasm is divided by a septum that grows perpendicularly. • The growth of the bulkhead will be followed by a transverse wall. • Then it will separate into two daughter cells (W4)
	<ul style="list-style-type: none"> • DNA will replicate into two copies of DNA that have the same properties. • There is a process of division in the cell wall and cytoplasm which will form a dividing wall or septum and become the boundary between the two cells. • Then the septum is fully formed • Formed two new cells that have identical properties. (W5)

Figure 2. is an example of a student concept map at level 1 (emergent) where student scores are only <25% of the reference concept map. Figure 3. is an example of a student concept map at level 2 (transition), where student scores only reach 25-50% of the reference concept map. Then figure 4 is a concept map of students at level 3 (close to extend), where the first concept score of students reaches 51-75% of the reference concept map.

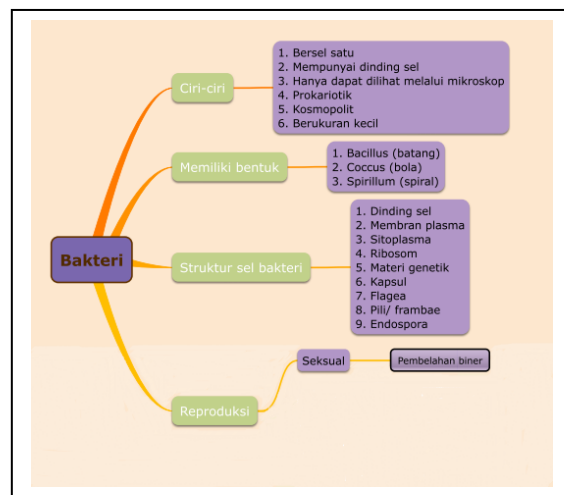


Figure 2. Student' Concept Map Level 1 (emergent)

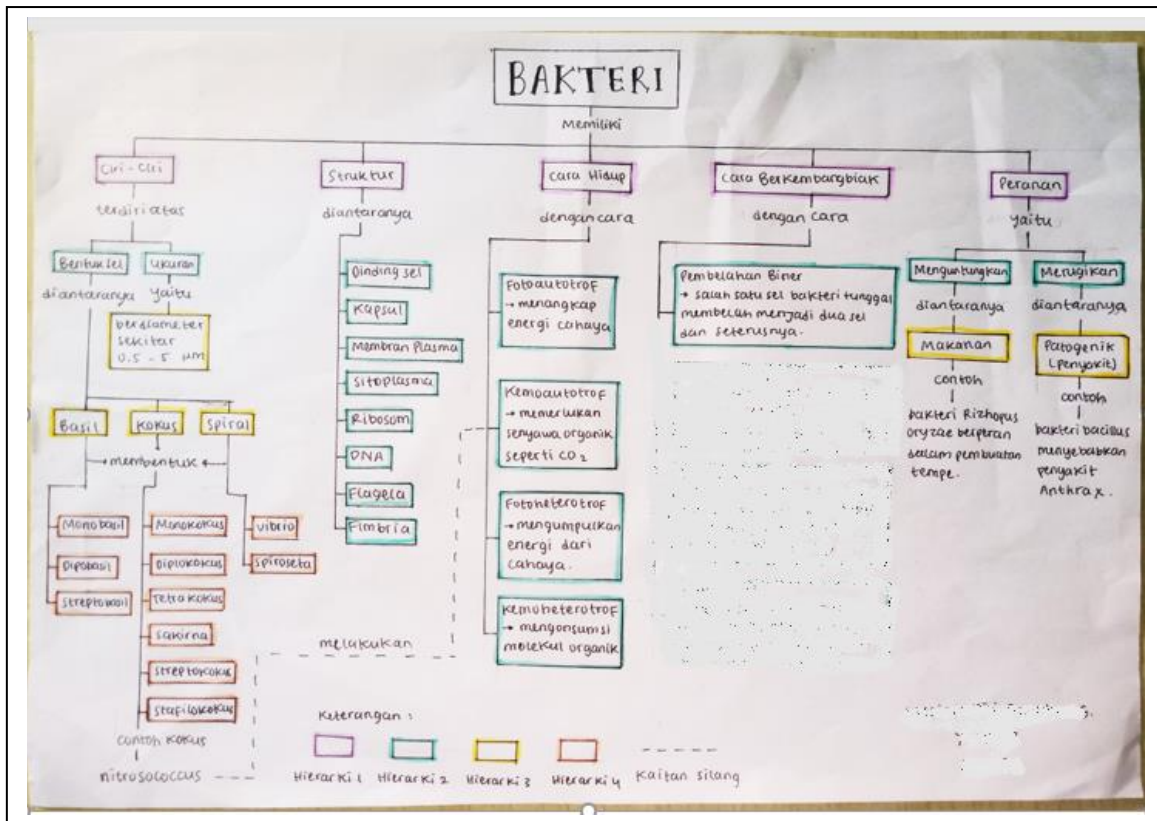


Figure 3. Student' Concept Map Level 2 (transitional)

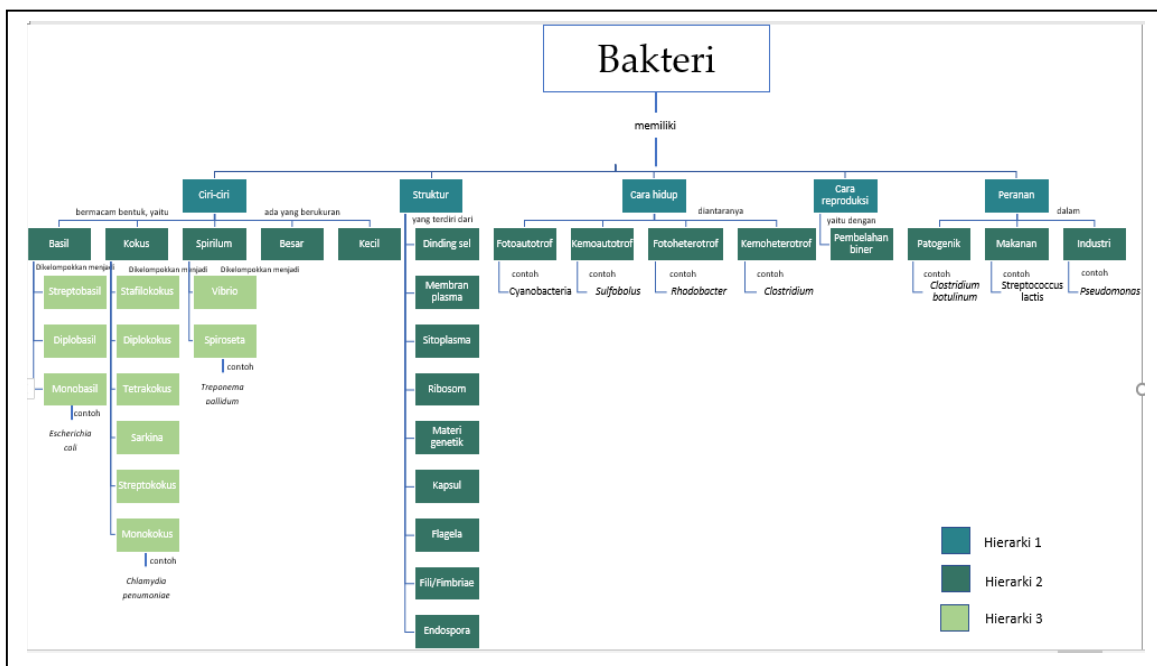


Figure 4. Student' Concept Map Level 3 (close to extend)

Based on Table 3, the most dominant mental models of students are at the D4/W2 level for the concept of bacterial structure and reproduction. The mental model achieved by students is still quite low, especially through writing tests. The description of students' mental models is still not close to the mental models of experts. Students still cannot describe the structure and

reproduction of bacteria correctly and completely. Dominant students describe the structure of bacteria by listing 5-8 cell components, from what should be 9 cell components and for the concept of bacterial reproduction, students only describe 3 of the 4 stages of bacterial reproduction. In addition, the mental model of students through the writing test is still low at level D2. Students have not been able to explain the structure and stages of bacterial reproduction correctly. Most students misunderstood the structure and reproduction of bacteria so that it is not relevant to what it should be. The results of the students' mental models through the drawing-writing test were supported by the results of interviews which explained that it was easier for students to represent through pictures than writing because pictures were easier to remember than writing. This is in accordance with the research conducted by Hamdiyati et al. (2017) it seems that through an image, mental models of microorganisms are easily represented. This is also related to the learning style that is usually done by students, namely the visual learning style, where students become better at understanding and storing information or concepts through pictures. Students who integrate two learning resources in the form of text and images have a better answer if they only use one. Likewise with videos that involve audio-visuals, allowing people to quickly understand the overall structure of the subject (Zhao et al., 2020).

The description of the mental model of students through the drawing-writing test which is still low is also supported by the description of the mental model through the concept map which is still at the lowest level of level 1 emergent (Figure1). Students are not used to making concept maps, so only a few concepts appear on concept maps. In addition, many students have not included propositions on the concept map so that the concept map becomes meaningless. Then many students do not include cross-links and examples on the concept. According to Novak and Gowin (1984), students need practice in conceptualizing, doing it repeatedly, so that they can clearly define the key concepts or propositions to be learned and connect new knowledge with what they already know. Dahar (2006) explains that removing concepts, then connecting concepts with conjunctions into meaningful propositions, is not an easy task. Students must really learn, train themselves to produce concept maps that are meaningful for themselves.

The mental model formed by students is strongly influenced by the learning carried out. When learning at school about the shape of bacterial cells, students learn by using the Make a Match learning model. Due to the short time, when students match the picture cards with the answer cards it happens quite quickly, so the information received is not well embedded in the students' minds. Then for the next material, students do self-study because the learning meeting in class has been completed. The independent learning carried out by these students is one of the factors that can influence the formation of mental models of bacteria. Less learning in class will be replaced and will also increase if students do independent learning. Vice versa, when students do not repeat the learning independently, the mental model will not be formed. In addition, the learning resources used by students can also add to students' concepts so that the mental model formed becomes better. When students are able to use various sources to increase knowledge, the mental model formed will develop and vice versa. Buckley and Boulter (2000) also explain that mental models combine diverse knowledge from various sources, direct experience with phenomena, through teaching, learning, and informal educational experiences, all of which can contribute to the formation of mental models. Bunting et al. (2006) explains

that each student creates a different cognitive or mental model, based on prior knowledge, existing ideas, and past experiences in order to interpret and explain an event. Complex mental operations are necessary to build comprehension of the concepts. This mental operation exemplified as processing information, structuring in the mind, thinking, and mental model development (Gunes, 2022). The lack of learning carried out can affect the process of forming students' mental models. Sreelohor et al. (2022) stated the first stage to change students' misconceptions is a psychological base, including constructivist theory and cognitive theory (mental model).

Conclusion

Based on the research that has been done, it can be concluded that the students' mental models through drawing-writing tests, concept maps and supported by interviews are still in the low category. Students have not been able to represent the concept of bacteria well. The most dominant mental model through the writing-drawing test is D4/W2 (the picture has several errors/wrong or irrelevant writing) contained in each concept. The mental model picture obtained is that students draw 5-8 cell components and explain the function of the bacterial structure. Then students only describe the 3 stages and only explain the reproduction of bacteria in general. The mental model of students through concept maps is more dominant at level 1 (emergent) which has not yet approached the mental model of an expert.

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Credit Authorship Contribution Statement

Yanti Hamdiyati: Conceptualization, Methodology, Visualization, Formal analysis, Writing – original draft, Resources, Writing – review & editing, Supervision, Project administration. **Taufik Rahman:** Conceptualization, Resources, Writing – review & editing, Supervision. **Ratna Dwi Rahmawati:** Conceptualization, Methodology, Formal analysis, Writing – original draft.

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