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Identification of Student Misconceptions in General Biology Courses using Four Tier Multiple Choice Tests Containing High Order Thinking Skills

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Abstract: This research aims to identify misconceptions of biology education students in the General Biology course. The method used in this research uses quantitative descriptive. The sample used in this research was Biology education students who had taken General Biology courses consisting of students in semesters 3, 5, and 7. Data collection was carried out using a test in the form of General Biology questions in a four-tier multiple-choice diagnostic format containing high-order thinking skills, totaling 35 questions. The research results showed that the percentage of misconceptions in each class was 43.80% (semester 3), 33.93% (semester 5), and 29.46% (semester 7). The highest percentage of misconception categories among third-semester students was found in the digestive system material (57.78%), fifth-semester students in ecology material (56.67%), and seventh-semester students in ecological material (40.00%). Misconceptions in students could be caused by students not being used to working on this type of question HOTS. To be able to answer correctly, students must be able to analyze and relate the data or information in the question to existing concepts.

Keywords: Biology; Four-Tier Multiple-Choice Diagnostic; High Order Thinking Skills; Misconceptions

Introduction

Students in the Biology Education study program are students who are prepared to become biology teachers in high school. According to the Regulation of the Minister of National Education No. 16 of 2007, professional competence is one of the competencies that should be well understood by every candidate teacher. Professional competencies that teachers must have are understanding the scientific concepts correctly, having clear motivation and direction, and being able to increase student motivation and achievement of learning outcomes (Awal et al., 2018; Pristyadi & Anam, 2020). Teachers must become proficient in a variety of learning strategies and be able to adapt them to meet the needs of their students in order to select lessons that will demonstrate and enhance students' learning abilities (Novallyan et al., 2023). Teachers who understand their scientific concepts well and correctly will find it easier to explain a concept to the student (Sari et al., 2024).

The ability to understand scientific concepts correctly is not only acquired when you become a teacher but also begins when you are still a student. A Lack of ability to understand scientific concepts can have a fatal impact on the learning process (Shidik & Tae, 2022). Misconceptions are one of the consequences of a lack of understanding of concepts. Misconceptions can be defined as concepts that have meanings that do not match scientific explanations (Bahar, 2003; Sholihat et al., 2017). Misconceptions can be caused by teachers, students, and textbooks (Mu'arikha & Qomariyah, 2020; Ritonga et al., 2017; Yuliati, 2017);. Experience and learning methods contribute to student misconceptions ((Kurniasih, 2017).

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Misconceptions can occur when someone tries to understand information (Gooding & Metz, 2011; Utami & Khotimah, 2023). Initial concepts that students bring to the classroom can take the shape of theories that run counter to scientific advancements in society (Maulana et al., 2023). Misconceptions that occur continuously can interfere with the formation of scientific concepts in students and teachers (Kartimi et al., 2021). Some studies on misconceptions in the field of biology found in students include ecosystem (Ristanto et al., 2023), genetic concepts (Wulandari et al., 2021), cell biology (Awal et al., 2018), the human digestive system (Cardak, 2015), human circulatory system (Sungur et al., 2001), evolution (Picardal & Picardal, 2023) and biotechnology (Idris et al., 2024). In general, the basic concepts that cover all of this are studied in the General Biology course.

Misconceptions that occur in this course can cause misconceptions in subsequent courses. Detection of misconceptions in General Biology courses is expected to help prevent misconceptions in subsequent courses. Misconceptions can be detected using diagnostic tests (Hunaidah et al., 2022). Diagnostic tests to detect student weaknesses during lectures (Pratiwi et al., 2023; Sholihat et al., 2017). Diagnostic tests used to detect misconceptions are interviews, simple multiple-choice tests, tiered tests, and open tests. The methods often used to detect misconceptions are interviews 53%, open questions 34%, multiple choice 32%, and multiple-tier tests 13% (Gurel et al., 2015). Based on this data, the method that is least used to detect misconceptions is the multiple-tier test. Multiple-tier tests consist of three types, namely two-tier multiple-choice tests (Widiyatmoko & Shimizu, 2018), three-tier multiple-choice tests (Wahidah et al., 2019), and four-tier multiple-choice tests (Sholihat et al., 2017). Four-tier multiple-choice tests provide clearer information about students' level of understanding of a concept (Dirman et al., 2022).

Critical and creative thinking are two abilities that are essential in the twenty-first century (Jihannita et al., 2023). Both skills have an important role in adapting to change, and the ability to make the right decisions. These two skills are higher-order thinking skills. Being able to solve scientific questions is one of the higher-order cognitive abilities (Imaduddin et al., 2023). The questions used generally only measure aspects of knowledge and understanding (Brookhart, 2010; Maryani et al., 2022). In other words, questions should be of the HOTS type, which can assist higher-order thinking skills (Anggraeni & Sole, 2020). This type of question is designed to measure students' high-level thinking abilities (Susanti, 2023; Ulfah & Retnawati, 2023; Widana, 2017). The new Bloom's taxonomy categorizes high-level thinking skills as reasoning level C4 (analyzing), C5 (evaluating), and C6 (creating) (Listiani & Rachmawati, 2022). The levels of this taxonomy all involve critical or high-level thinking. Students who are able to think are those who can apply the knowledge and skills they have learned to new contexts (Hajaroh, 2021).

Based on this description, this study aims to identify student misconceptions found in general biology courses by using four-tier multiple-choice tests containing high-order thinking skills. It is hoped that the results of this research can provide an overview of student misconceptions in general biology courses. The misconceptions found should be a reference for improving students' understanding of the concept. In this way, it is hoped that existing misconceptions can be corrected immediately so that they are not carried over to the next course.

Method

This research is quantitative descriptive research. The sample in this study were students from the Bachelor of Biology Education study program at Muhammadiyah University of Bengkulu who had completed General Biology courses, consisting of students in semesters 3, 5, and 7. Data were collected using a test in the form of General Biology questions in a four-tier multiple-choice diagnostic format containing high-order thinking skills. The test consists of 35 questions that require knowledge of 13 different topics: diversity of living things, ecology, cells, movement system, circulatory system, digestive system, respiratory system, excretory system, reproductive system, metabolism, genetics, evolution, and biotechnology.

There are four tiers of questions in a single question. There are four possible answers to a multiple-choice question on a high order thinking skill (HOTS) in the first level. The second level represents the degree of confidence in the first level's response options, which are sure and not sure. The third level is in the form of explanations or justifications for selecting answers at the first level which consists of four answer choices. The fourth level is the level of confidence of the answers chosen at the third level which consists of two answer choices, namely sure and not sure. The category used to interpret student answers to the tests given can be seen in Table 1.

Table 1. Respond to the four tier multiple choice diagnostic test's choice decisions

1st tier	2nd tier	3rd tier	4th tier	Category
Correct	Sure	Correct	Sure	scientific knowledge
Correct	Sure	Correct	Not sure	Lack of knowledge
Correct	Not sure	Correct	Sure	Lack of knowledge
Correct	Not sure	Correct	Not sure	Lack of knowledge
Correct	Sure	Wrong	Sure	False Positive
Correct	Sure	Wrong	Not sure	Lack of knowledge
Correct	Not sure	Wrong	Sure	Lack of knowledge
Correct	Not sure	Wrong	Not sure	Lack of knowledge
Wrong	Sure	Correct	Sure	False Negative
Wrong	Sure	Correct	Not sure	Lack of knowledge
Wrong	Not sure	Correct	Sure	Lack of knowledge
Wrong	Not sure	Correct	Not sure	Lack of knowledge
Wrong	Sure	Wrong	Sure	Misconception
Wrong	Sure	Wrong	Not sure	Lack of knowledge
Wrong	Not sure	Wrong	Sure	Lack of knowledge
Wrong	Not sure	Wrong	Not sure	Lack of knowledge

Source: (Gurel et al., 2015)

Result and Discussion

The results of the analysis of students' understanding of general biological concepts are categorized into four categories, namely scientific knowledge, lack of knowledge, false (+/-), and misconceptions. Percentage of student understanding level in each semester can be seen in Figure 1. According to Figure 1, the percentage of students who scientific knowledge category in each class is 7.18% in the third semester, 9.32% in the fifth, and 6.38% in the seventh. According to the analysis's findings, 18.85% of students in the third semester, 41.37% in the fifth, and 44.23% in the seventh fall into the lack of knowledge category. In the third, fifth, and seventh semesters, 30.17%, 15.38%, and 19.94% of students were in the false (+/-) category. Students in the misconception category were 43.80% (semester 3), 33.93% (semester 5), and 29.46% (semester 7). The highest percentage for each category was scientific knowledge at 9.33% in semester 5, lack of knowledge at 44.23% in semester 7, false (+/-) category at 30.17% in semester 3, and the highest misconceptions were found in semester 3 at 43.80%.

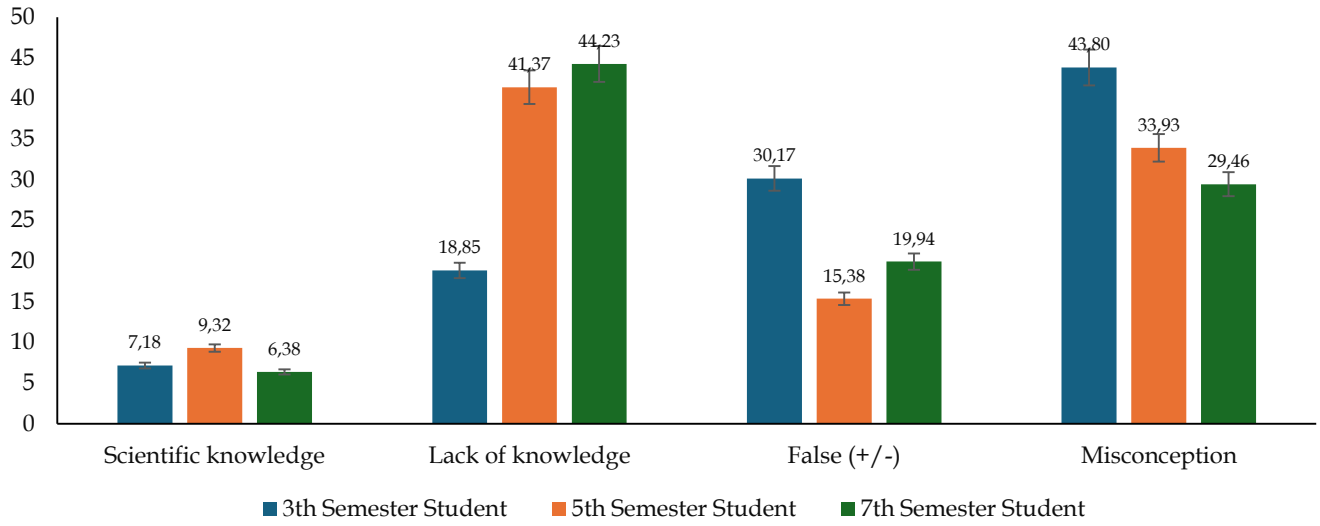


Figure 1. Percentage of student understanding level in each semester

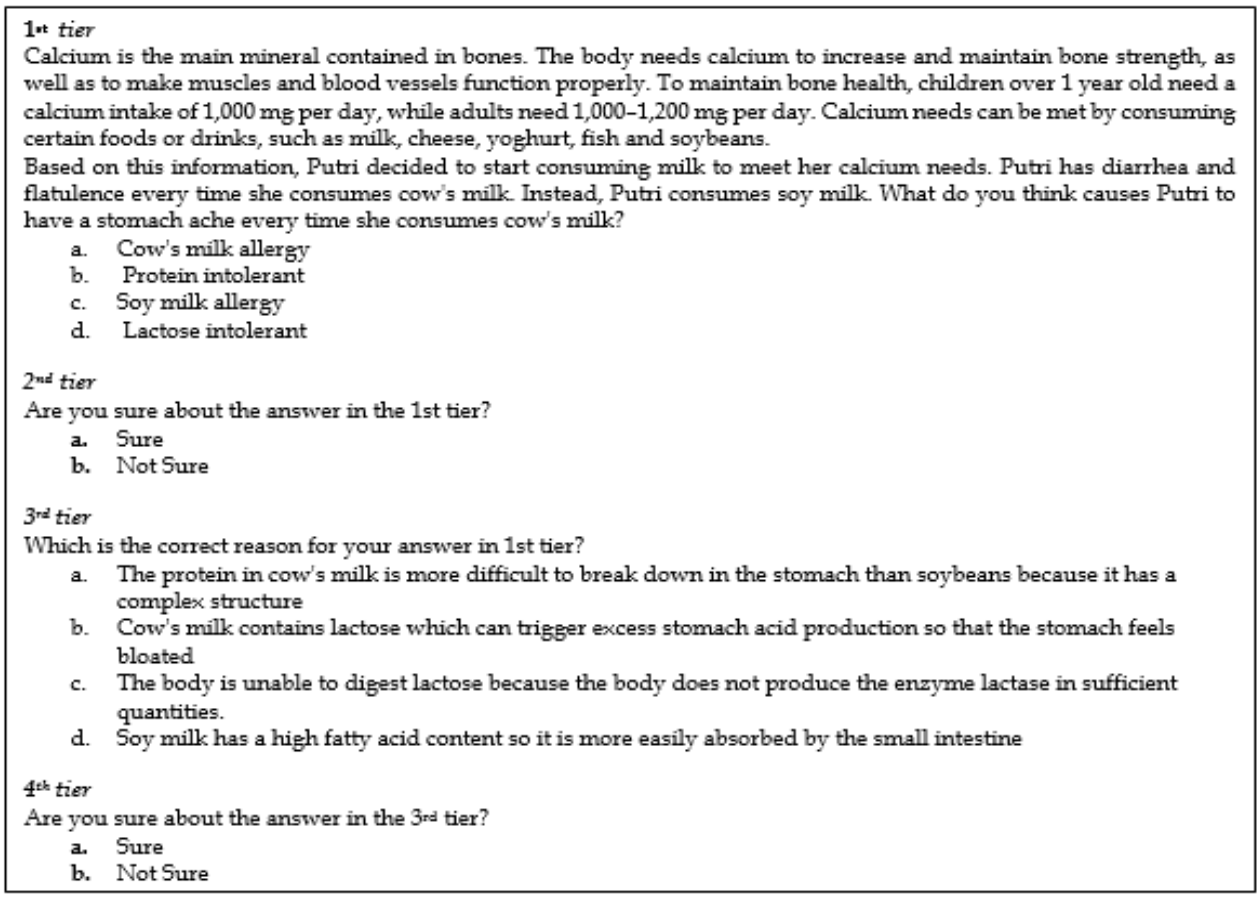
Misconceptions of 3rd Semester Students

The data was processed descriptively to identify the level at which students understood the concepts discussed in the general biology course, based on the pattern of answers from students in semester 3. Table 2 indicates the average percentage of knowledge level for students in third semester.

Table 2. The third-semester students' average percentage of understanding level

Subject Matter	Scientific knowledge	Lack of knowledge	False (+/-)	Misconceptions
Diversity of Living Things	11.11	24.44	26.67	37.78
Ecology	6.67	20.00	20.00	53.33
Cells	10.00	23.33	23.33	43.33
Movement System	13.33	13.33	40.00	33.33
Circulatory System	6.67	15.56	44.44	33.33
Digestive System	4.44	15.56	22.22	57.78
Respiratory System	6.67	15.56	28.89	48.89
Excretory System	0.00	6.67	36.67	56.67
Reproductive System	8.89	20.00	33.33	37.78
Metabolism	5.00	15.00	31.67	48.33
Genetics	5.00	20.00	28.33	46.67
Evolution	6.67	26.67	23.33	43.33
Biotechnology	8.89	28.89	33.33	28.89

Table 2 shows that scientific knowledge (13.33%) in the diversity of movement system material, lack of knowledge (28.89%) in the biotechnology material, false category (44.44%) in the circulatory system material, and misconceptions (57.78%) in the digestive system material are the highest percentages for each category. The highest percentage of misconceptions for third-semester students was found in question number 14 (73.33%) about the digestive system. Question number 14 can be seen in Figure 2.



1st tier

Calcium is the main mineral contained in bones. The body needs calcium to increase and maintain bone strength, as well as to make muscles and blood vessels function properly. To maintain bone health, children over 1 year old need a calcium intake of 1,000 mg per day, while adults need 1,000–1,200 mg per day. Calcium needs can be met by consuming certain foods or drinks, such as milk, cheese, yoghurt, fish and soybeans.

Based on this information, Putri decided to start consuming milk to meet her calcium needs. Putri has diarrhea and flatulence every time she consumes cow's milk. Instead, Putri consumes soy milk. What do you think causes Putri to have a stomach ache every time she consumes cow's milk?

a. Cow's milk allergy
b. Protein intolerant
c. Soy milk allergy
d. Lactose intolerant

2nd tier

Are you sure about the answer in the 1st tier?

a. Sure
b. Not Sure

3rd tier

Which is the correct reason for your answer in 1st tier?

a. The protein in cow's milk is more difficult to break down in the stomach than soybeans because it has a complex structure
b. Cow's milk contains lactose which can trigger excess stomach acid production so that the stomach feels bloated
c. The body is unable to digest lactose because the body does not produce the enzyme lactase in sufficient quantities.
d. Soy milk has a high fatty acid content so it is more easily absorbed by the small intestine

4th tier

Are you sure about the answer in the 3rd tier?

a. Sure
b. Not Sure

Figure 2. Question number fourteen

The combination of answers chosen by students in the 1st tier and 3rd tier for question number 14 can be seen in Figure 3.

There are five answer combinations formed from student choices. Students in tiers 1 and 3 most commonly selected the answer combinations (a-a) and (a-b), each at 37%. Students believe the cause of stomach ache after consuming cow's milk is (a) cow's milk allergy, because (a) the protein in cow's milk is more difficult to break down in the stomach than soybeans

because it has a complex structure. In addition, students also believe that the cause of stomach ache after consuming cow's milk is (a) cow's milk allergy, because (b) cow's milk contains lactose which can trigger excess stomach acid production so that the stomach feels bloated. The correct answer is (d) lactose intolerant, for the reason that (c) the body is unable to digest lactose because the body does not produce the enzyme lactase in sufficient quantities. The misconception is caused by students' lack of knowledge about the difference between lactose intolerance and allergies to cow's milk (Costanzo & Canani, 2019; Walsh et al., 2016).

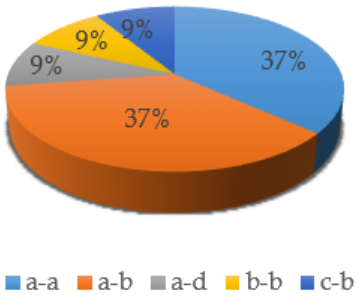


Figure 3. Combination of 1st tier and 3rd tier answers to question number fourteen

Misconceptions of 5th Semester Students

Based on the pattern of responses from students in semester 5, the data was analyzed descriptively to determine the degree to which students learned the topics covered in the general biology course. The average proportion of students' fifth semester knowledge level is displayed in Table 3.

Table 3 shows that scientific knowledge (31.11%) is the greatest proportion for each category in the diversity of living things material, followed by lack of knowledge (46.67%) in the excretory system material, and false category (26.67%) in the diversity of living things material items, and 56.67% in misconception the ecology content. The highest misconception for 5th Semester Students was found in question number 4 (66.67%). Students analyze the potential effects of large-scale fishing on marine ecosystems in question number 4. The stimulus for question number 4 is an image of marine ecosystem's food web. Question number 4 can shown in Figure 4.

Table 3. The fifth-semester students' average percentage of understanding level

Subject matter	Scientific knowledge	Lack of knowledge	False (+/-)	Misconceptions
Diversity of living things	31.11	20.00	26.67	22.22
Ecology	6.67	33.33	3.33	56.67
Cells	13.33	30.00	20.00	36.67
Movement system	13.33	26.67	13.33	46.67
Circulatory system	4.44	44.44	17.78	33.33
Digestive system	6.67	51.11	13.33	28.89
Respiratory system	8.89	40.00	17.78	33.33
Excretory system	0.00	46.67	23.33	30.00
Reproductive system	4.44	55.56	13.33	26.67
Metabolism	167	43.33	16.67	38.33
Genetics	1.67	53.33	10.00	35.00
Evolution	6.67	53.33	6.67	33.33
Biotechnology	22.22	40.00	17.78	20.00

There are two answer combinations, (d-a) and (d-d). The highest combination of answers in the 1st tier and 3rd tier is (d-d) at 80%. The combination of answers between the 1st tier and 3rd tier in question number 4 can presented in Figure 5. Figure 5 shows that 80% of students believe that the impact that might occur on the marine ecosystem if large-scale fishing is (d) Fish populations will become extinct because (d) Fish cannot reproduce well because they are hunted on a large scale. The correct answer is (b) The seagull population has drastically reduced, because (b) Massive fishing causes the seagulls to lack food. Based on the picture of the food web in question, students understand that the fish population will become extinct because fish cannot reproduce well because they hunt on a large scale.

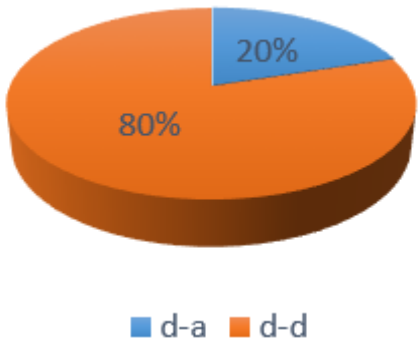


Figure 4. Combination of 1st tier and 3rd tier answers to question number four

This misconception is caused by students not understanding the interaction of food and food in the food web. Misconceptions about this concept can be corrected by displaying a picture of a food web and completing it with a teacher's explanation. Pictures in the learning process can communicate concepts so that it becomes more effective because students can see the images being taught by the teacher (Afidah, 2020). Using images as a learning medium can help students understand concepts that are difficult for students to understand (Hanna et al., 2016).

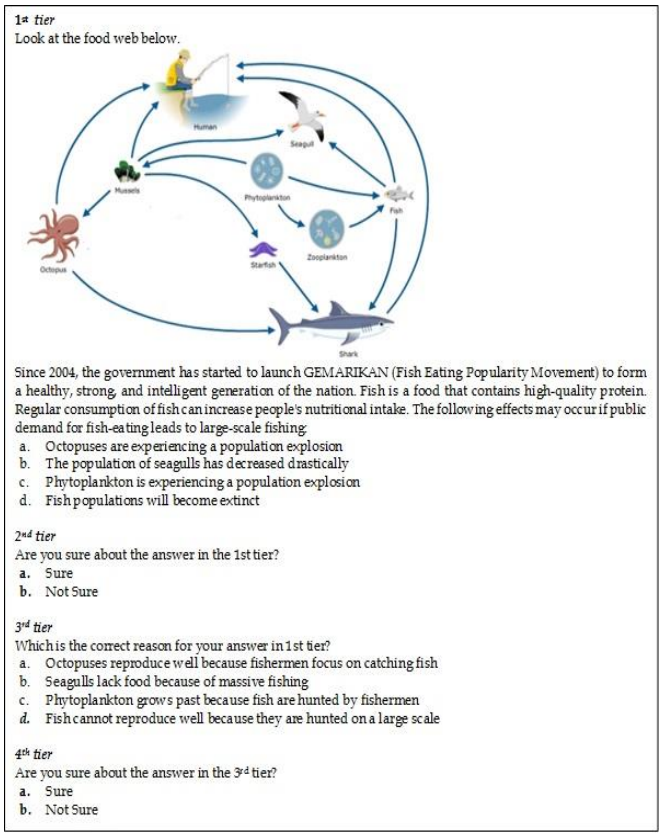


Figure 5. Question number four

Misconceptions of 7th Semester Students

To find out the level at which students understand the subjects studied in the general biology course, a descriptive analysis of the data was conducted based on the answers from students in semester 7. Table 4 shows the average percentage of student's knowledge in the seventh semester.

Table 4 shows that scientific knowledge (20.00%) in the Movement System material, lack of knowledge (57.50%) in the Metabolism and Genetics material, false category (26.67%) in the Diversity of Living Things material, and misconceptions (40.00%) in the Ecology material are the highest percentages for each category. Students in semester 7 had the most misconceptions (45.00%) in question number 5, 7, and 12. Information about the oil spill accidents that happened in Indonesia was given as a stimulus in question number five. The purpose of this question is to assess students' knowledge of how to formulate cleanup strategies for oil spills in the aquatic environment. Figure 6 displays the combination of responses from the first and third tiers for question number 5.

The most common answer combination was (d-d) at 67%. Students understand that the effort to clean the aquatic environment from oil spills is bioremediation using Pseudomonas sp bacteria because Pseudomonas sp bacteria can break down oil hydrocarbon bonds into CO_2 gas so that the environment becomes clean. The correct answer is (c) The oil spill in Karawang can be cleaned up with an oil boom, for the right reason (a) The sorbent can absorb the oil spill into a solid so that it is easier to collect and dispose of. In this question, there were no students in the concept understanding category. The misconception about this question is that the stimulus given in the question is unfamiliar to student life. The stimulus provided should be close to students' lives (Widana, 2017).

Table 4. The seventh-semester students' average percentage of understanding level

Subject matter	Scientific knowledge	Lack of knowledge	False (+/-)	Misconceptions
Diversity of living things	11.67	30.00	33.33	25.00
Ecology	5.00	35.00	20.00	40.00
Cells	10.00	40.00	15.00	35.00
Movement system	20.00	20.00	25.00	35.00
Circulatory system	3.33	46.67	25.00	25.00
Digestive system	1.67	46.67	15.00	36.67
Respiratory system	5.00	41.67	28.33	25.00
Excretory system	5.00	52.50	15.00	27.50
Reproductive system	10.00	51.67	15.00	23.33
Metabolism	5.00	57.50	10.00	27.50
Genetics	1.25	57.50	17.50	23.75
Evolution	0.00	47.50	15.00	37.50
Biotechnology	5.00	48.33	25.00	21.67

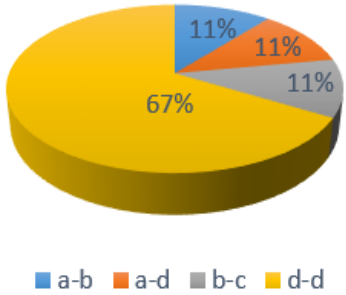


Figure 6. Combination of 1st tier and 3rd tier answers to question number five

Students in 7th semester have numerous misconceptions about Question 7. The data in a table showing the results of experiments A and B. It is used as the stimulus for question number 7. In experiment A, Potato holes were filled with sugar water, and the potatoes went under in fresh water. In the second experiment, the hollowed potatoes were filled with fresh water and then soaked in sugar water. Students use the information to determine the correct conclusion. Figure 7 shows the combination of responses for question number 7's first and third tiers.

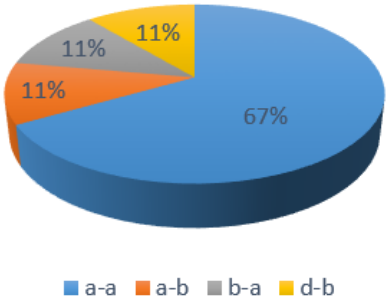


Figure 7. Combination of 1st tier and 3rd tier answers to question number seven

The most common answer combination was (a-a) at 67%. Based on the combination of answers most chosen by students, it shows that students concluded that (a) The volume of fresh water in experiment A increased while in experiment B it decreased for the reasons (a) The concentration of fresh water in experiment A was higher than the concentration of fresh water in experiment B. Misconception This concept is because students do not understand the concept of osmosis. Students have difficulty understanding new terms (Badenhorst et al., 2014). Misconceptions about the concept of osmosis are corrected by providing an understanding of osmosis and examples in everyday life. Practical activities can also help students understand this concept more easily (Sikumbang et al., 2020; Susanti et al., 2022).

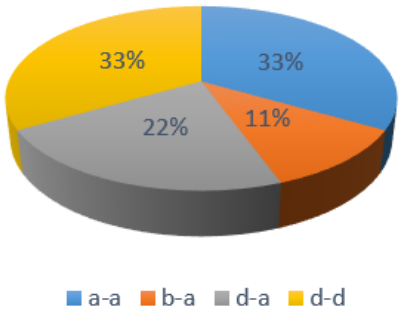


Figure 8. Combination of 1st tier and 3rd tier answers to question number twelve

Question number 12 also had the highest misconception categories among 7th-semester students. The stimulus for question number 12 was a table of food menus for people on a mayo diet for 13 days. In this question, students analyze the factors that cause people on a Mayo diet to lose weight drastically based on the menu data presented. The combination of 1st-tier and 3rd-tier answers in question number 12 is presented in Figure 8.

Students often select two answer combinations, (a-a) and (d-a), each at 33%. Answers from students indicate they understand why people following the Mayo diet can lose a significant amount of weight (a) Because low-sugar drinks are used by the body as a direct source of energy, they help people lose weight more quickly; (b) People following the Mayo diet only drink Tropicana Slim sugar. Misconceptions in this question can be because of students' ability to read tables and relate them to appropriate concepts (Mustain, 2015); (Setiani & Suyitno, 2021).

Conclusion

Based on the research results, it can be concluded that student misconceptions in biology courses are generally found in all groups in the research sample. The highest percentage of misconceptions was found in 3rd-semester students and the lowest in 7th-semester students. The material with the most misconceptions was digestion material in 3rd-semester students and ecology material in 5th and 7th-semester students. Misconceptions in students could be caused by students not being used to working on this type of question HOTS. To be able to answer correctly, students must be able to analyze and relate the data or information in the question to existing concepts.

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Author Contributions

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Conflicts of Interest

The authors declare no conflict of interest.

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