Biosfer: Jurnal Pendidikan Biologi

Mastery concepts and misconceptions in biotechnology courses with a three tier diagnostic test

Tengku Idris[1,2] , Topik Hidayat[3*], Adi Rahmat[4]

[1] Science Education, Faculty of Mathematics and Science Education, Universitas Pendidikan Indonesia, Indonesia
[2] Biology education, Faculty of teacher training and education, Universitas Islam Riau, Indonesia
[3] Biology, Faculty of Mathematics and Science Education, Universitas Pendidikan Indonesia, Indonesia
[4] Biology Education, Faculty of Mathematics and Science Education, Universitas Pendidikan Indonesia, Indonesia

*Corresponding author: topikhidayat@upi.edu

A R T I C L E   I N F O

A B S T R A C T

This research aims to determine the mastery of concepts and misconceptions of students in the Biology Education Study Program wich is in Pekanbaru. This type of research is survey research with a porpusive sampling type. The population of the study was all students who had taken biotechnology courses, while the research sample was 6th semester students who had just completed biotechnology courses in the previous semester. The total research sample was 32 students. The instrument used to measure mastery of concepts and misconceptions is a diagnostic test with 20 multiple choice questions accompanied by reasons and level of belief. The questions are given using a Google form and students work on the questions during class and are given 90 minutes.The research data were analyzed descriptively. Based on the results showed that for indicator 1 30.01% of students understood the basic concepts of biotechnology well and 55.63 had misconceptions. In indicator 2, only 5% of students understood the concept of biotechnology process while 64.38% had misconceptions and 29.38 did not understand the concept. Indicator 3, as many as 10.63% of students understand the concept of conventional and modern biotechnology characteristics and 59.38% of students have misconceptions and 25.63% do not understand the concept while indicator 4 as many as 30.63% of students understand the examples of biotechnology products while still 43.13% have misconceptions and 22.50% still do not understand the concept. Students' mastery of concepts in biotechnology courses is in a very low category and while more than half of the students still experience misconceptions and do not understand the concepts.

INTRODUCTION

Riau Islamic University is one of the largest universities in LLDIKTI X with 34 study programs in the excellent, very good and good categories. One of the study programs in the excellent category is the Biology Education Study Program. This study program aims to produce prospective biology teachers who are professional in the field of pedagogy and content. Strengthening pedagogy is obtained by providing pedagogical support courses for both junior high school and high school levels. As for biological content, courses are presented that equip them to be able to teach and research in the field of biology (Kaplar et al., 2021). One of the biology that is a compulsory subject is biotechnology. Biotechnology is taught in semester 5 because this material requires other prerequisite courses such as cell biology, physiology, genetics biochemistry and other courses (Tim dosen, 2020).

Biotechnology is defined as the use of biological systems, consisting of living organisms or their parts, to obtain knowledge, goods and services of interest to society. The field of biotechnology covers a wide range of disciplines: from Life Sciences, such as Biochemistry, Genetics or Microbiology, to Social Sciences, including Economics or Law. In addition, the field of Biotechnology also requires the use of tools from various branches of Engineering. In particular, the study of biotechnology in industrial applications also demands an understanding of chemical and physical processes in Chemical Engineering (Ripoll et al., 2023; Utomo et al., 2020; (Hilgartner, 2017; Smith, 2012). Biotechnology subject is one of the compulsory subjects for educator-producing universities in Indonesia (LPTK) in the biology education study program. This course is usually taught in the upper semester or peak because it is considered material with high complexity because it requires basic concepts from several other subjects (Goh & Sze, 2019).

Biotechnology is difficult for students to master because of the characteristics and requirements for mastering other subjects. Many students think that biotechnology is a biological concept using high-level technology, even though biotechnology also uses simple concepts and is easy to apply. For example, if asked what are the examples of biotechnology, students will tend to give examples of cloning, genetic engineering, IVF and others. The examples given by students are not wrong, but this shows that students have the concept of biotechnology using high-level technology. Or there are also students who believe that all activities that use living things are called biotechnology. This concept is clearly very wrong and contrary to the basic concept of biotechnology. Errors that are believed to be true by students are called misconceptions. Misconception is a term that refers to the difference in thinking between the concepts that students have and the concepts from scientific theories determined by experts (Gurel et al., 2015).

Misconceptions are a big problem in learning, student mistakes in understanding a concept that is believed to be true are very difficult to change. For prospective teachers, misconception is the biggest enemy because mistakes that are believed to be true will be passed on to their students and will become public knowledge. For this reason, misconceptions must be immediately and solutions sought. Several methods that can be used to measure misconceptions are Three tier (E. A. Lestari et al., 2021; A. Lestari & Susantini, 2020; Shalihah et al., 2019; Shalihah et al., 2019; Jubaedah et al., 2017), Certainty of Response Index (CRI) (Mustakim et al., 2015)(Jago Duda et al., 2020), question (Bradshaw & Templin, 2014; Suhandi et al., 2008), Concept Map (Zubaidah & Pangestuti, 2016) and Interview (Hidayah et al., 2018).

Several researchs have succeeded in developing diagnostic test instruments to reveal misconceptions or misconceptions in students whose results can be known quickly and accurately, including CRI (Hasan et al., 2014), two-tier multiple choice (Treagust, 1988),, multi-choice three-tier doubles (Pesman & Eryilmaz, 2010). The diagnostic test instrument developed by Eryilmaz & Surmeli (2002) is a continuation of the Two-tier Multiple Choice development developed by Treagust, 1988, can reveal misunderstandings or misconceptions in students better than one-tier or two-tier diagnostic tests (Gurel et al., 2015)

In its development, the Three-Tier Test developed by (Pesman & Eryilmaz, 2010) explains that the test in the form of a Three-Tier Test is a combination test of two-tier and CRI, and this test is very easy for high school teachers to use because this test is very suitable. and accurate in measuring student misconceptions, this test can also monitor the progress of student learning success because the scores produced in this test are valid and reliable so that this test can measure the percentage of students' understanding level. This test can also distinguish between students who experience misconceptions and do not understand the concept (lack of knowledge) by adding the previous two-tier questions.

METHODS
Research Design
The research is a survey study (Creswell, 2015) aimed at identifying the knowledge and miskonceptions about biotechnology concept among prospective biology teachers who are currently enrolled in the biology education program at the faculty teacher training and education, wich is in Pekanbaru, city.

Population and Samples
The research sample was obtained using a proportional sampling technique. The selected sample was taken from students who had just finished taking biotechnology courses in the previous semester. The population of this study comprises all biology education students who have taken the biotechnology course. The research sample cosisstes of 32 students in their sixth semester who have completed the biotechnology course during their fifth semester. The sample is composed pf 30 female and 2 male students.

Instrument
The instrument used to measure the students' abilities and misconceptions in the biotechnology course is a diagnostic test, comprising 20 multiple -choice questions, each accompanied by a reason and confidence level. The instrument has been validated by expert. The design of the instrument is based on the course indicator, as shown in the table below.

Table 1.
Grid of Misconception Questions

No	Indicator	Subject	No item
1.	Students understand the basic concepts of biotechnology	Cell biology Gen genome genetics Metabolism	1, 2, 3, 4, 5
2.	Students understand the processes that occur in biotechnology	Principle of totipotency Competency principle Fermentation principle Principles of Recombinant DNA Principles of Genetic Engineering	6, 7, 8, 9, 10
3.	Students understand the characteristics of conventional and modern biotechnology	Characteristics of biotechnology Conventional biotechnology Modern biotechnology The difference between conventional and modern biotechnology	11, 12, 13, 14, 15
4.	Students can provide examples of biotechnology products	Plasmid Examples of conventional biotechnology Examples of modern biotechnology Monoclonal antibodies Plant tissue isolation method Vaccine	16,17,18, 19, 20

Procedure
Before data collection, the researcher prepared the research instrumen and validated it through expert validation. After finalizing the instrument, the researcher informed the student participants about the research objectives and the data collection process. Subsequenctly, the student were provided with the survey questin using google form. Data was taken after students completed biotechnology courses in the previous semester.

Data collection took place within the classroom, and the students were required to answer the instrumen within a 90-minute time frame. Throughout the data collection process, the students were supervised by an invigilator to ensure adherence to the guidelines and the integrity of the data. The data

was analyzed using the percentage technique, referring to the categories that were previously established in assessing misconceptions on the three tier diagnstic test instrumen. Subsequetly, ot was categorized to determine the percentages of students' mastery concepts and misconceptions. After completing the data analysis, the research conducted interviews regarding the research findings with several samples and lecturees who teach the biotechnology course. The procedure of research can be see in Figure 1.
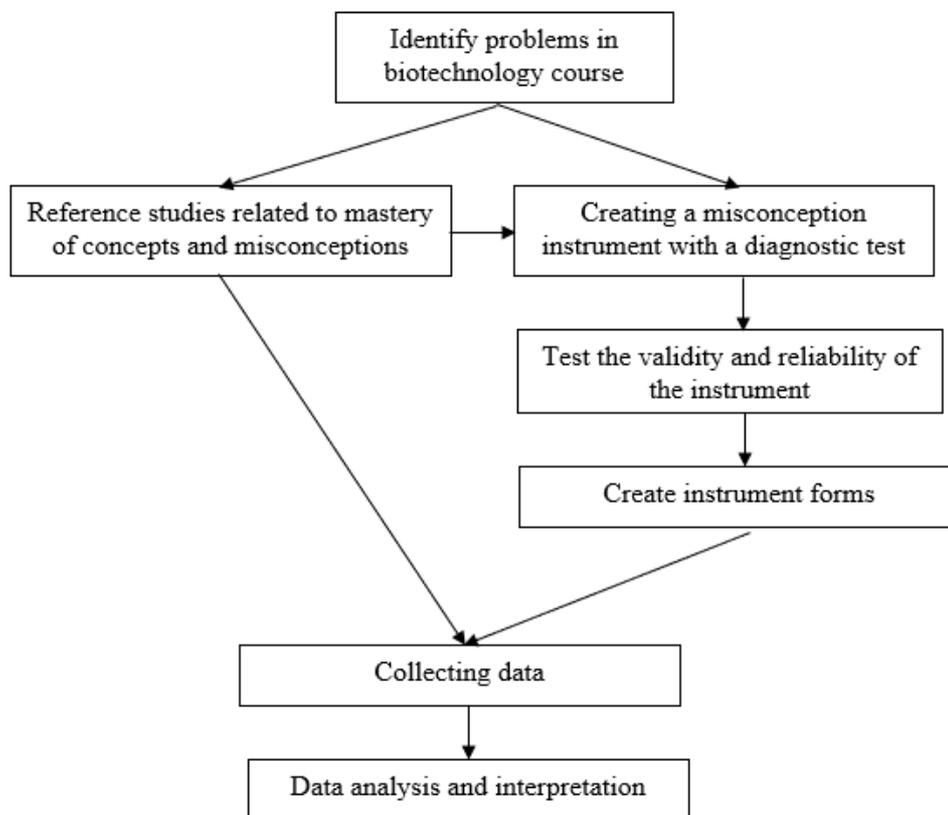
Figure 1. Procedure of Research

Data Analysis Techniques

The data were analysis using descriptive analysis with reference to categories of misconceptions in three tier diagnostic test instrument develop by expert. The categorization of concepts mastery and misconceptions can be seen in Table 2.

Table 2.
Categorization of Student Misconceptions

First tier	Second tier	Thried tier	Category
Correct	Correct	Certain	Understand Concept
Correct	Wrong	Certain	Misconceptions (false positive)
Wrong	Correct	Certain	Misconceptions (false negative)
Wrong	Wrong	Certain	Misconceptions
Correct	Correct	uncertain	Guessing (no confidence)
Correct	Wrong	uncertain	Don't understand the concept
Wrong	Correct	uncertain	Don't understand the concept
Wrong	Wrong	uncertain	Don't understand the concept

Source: (Istiyani et al., 2018)

The research data was then categorized to obtain the percentage of misconceptions using the persentage formula.

RESULTS AND DISCUSSION

Based on the results of the analysis that has been carried out, the results of concept mastery and

misconceptions of Biology Education Study Program students can be explained according to each indicator as follows:

1. Students understand the basic concepts of biotechnology

The first indicator in measuring students' mastery of concepts and misconceptions is that students are expected to understand the basic concepts of biotechnology. In biotechnology courses, many concepts from various disciplines must be mastered by students, such as those from cell biology, molecular biology, genetics and biochemistry courses and others. The results of student mastery and misconceptions can be seen as follows Tabel 3.

Table 3.
Mastery of concepts and misconceptions in the first indicator

Item No	Percentage			
	Understand Concept	**Misconceptions**	**Guessing**	**Don't understand the concept**
1	6.25	71.90	15.60	6.25
2	53.13	21.88	9.375	15.63
3	31.25	56.25	3.125	9.37
4	12.50	78.10	3.13	6.25
5	46.90	50.00	3.13	0.00
Average	30.01	55.63	6.80	7.50

Based on Table 3, it can be seen that in the indicator questions about understanding the basic concepts of biotechnology, only 30.01% of students understand the concept well. While 55.63% of students are in the category of misconceptions. Based on the table, it can be seen that in questions with the concept of cell biology and metabolism, the least students understand and the most experience misconceptions. While questions related to genetics and protein synthesis are the most understood by students and have few misconceptions. From these results it shows that only a few students guessed in answering the questions and for the category of not understanding the biggest concept on the genetic theme.

2. Students understand the processes that occur in biotechnology

In indicator 2, students test their knowledge of the processes that occur in biotechnology. In this indicator there are 5 questions that are given related to biotechnology processes including the principles of competence, totipotency, fermentation, recombinant DNA and genetic engineering. Student mastery of concepts and misconceptions can be seen in Table 4.

Table 4.
Percentage of Student Mastery of Concepts and Misconceptions in Indicator 2

Item No	Percentage			
	Understand Concept	**Misconceptions**	**Guessing**	**Don't understand the concept**
6	31.1	68.8	0.00	28.10
7	0.00	65.6	0.00	34.40
8	18.8	53.1	6.25	21.90
9	0.00	84.4	0.00	15.60
10	3.13	50.00	0.00	46.90
Average	5.00	64.38	1.25	29.38

Based on the table above it shows that on this indicator student knowledge is still very low with an average of 5% meaning that only 2 people really understand the concept. Questions about totipotency in animal cells (problem 7) and recombinant DNA (problem 9) were not able to be answered correctly by the students. When viewed from misconceptions, this indicator is the indicator with the highest misconception with a percentage of 64.38%. when viewed from the item items, then question number 9 related to genetic engineering gets the highest percentage, namely 84.4%. of the five questions, almost all questions did not indicate students guessed the answers to the questions with a percentage of 1.25%. besides that, 29/38% of students still do not understand the concept of processes that occur in

biotechnology.

3. Students understand the characteristics of conventional and modern biotechnology

In addition to understanding the basic concepts of biotechnology and the processes that occur in biotechnology, students are also tested for their mastery of the concepts regarding the characteristics of conventional biotechnology and modern biotechnology. The results of data analysis can be seen in Table 5 below.

Table 5.
Percentage of Student Mastery of Concepts and Misconceptions in Indicator 3

Item No	Percentage			
	Understand Concept	**Misconceptions**	**Guessing**	**Don't understand the concept**
11	12.50	75.00	0.00	12.50
12	0.00	65.60	0.00	34.40
13	28.10	53.10	12.50	6.25
14	0.00	59.00	3.10	38.00
15	13.00	44.00	6.30	38.00
Average	10.63	59.38	4.38	25.63

Based on Table 5, it shows that students' mastery of concepts on indicators of differences between conventional biotechnology and modern biotechnology is still very low with a percentage of 10.63. Questions about genetic engineering and transgenics could not be answered correctly by any one student and these two numbers also had the highest number of misconceptions. Misconceptions on this indicator are the second highest from other indicators with a percentage of 59.38%. while students who do not understand the concept get a percentage of 25.63%.

4. Students can provide examples of biotechnology products

In indicator 4, students are tested for their mastery of concepts about examples of both conventional and modern biotechnology products. In this indicator there are 5 questions about Plasmids, Examples of conventional biotechnology, Examples of modern biotechnology, Monoclonal antibodies, Tissue culture and Vaccines. The research results can be seen in Table 6.

Table 6.
Percentage of Student Mastery of Concepts and Misconceptions on Indicator 4

Item No	Percentage			
	Understand Concept	**Misconceptions**	**Guessing**	**Don't understand the concept**
16	84.40	9.38	3.13	3.13
17	40.60	53.10	0.00	6.25
18	18.80	31.30	6.25	43.80
19	9.40	53.00	6.30	31.00
20	0.00	68.80	3.13	28.10
Average	30.63	43.13	3.75	22.50

Based on Table 6 it shows that students' mastery of concepts about examples of biotechnology is still very low with a percentage of 30.63%. Of the 5 questions about biotechnology products, the highest percentage can be answered by students in question no 16 which relates to conventional biotechnology products with a percentage of 84.40%. while item No. 20 about vaccines was not able to be answered by a single student. In this indicator, 43.13% of students experience misconceptions with the highest percentage in item number 20. Apart from misconceptions, there are still students who do not understand the concept with an average percentage of 22.50%.

5. Mastery of Concepts and Misconceptions of Biology Education Students in the Biotechnology Course

Mastery of concepts is the ability of students to understand the concepts being taught who have logical reasons for choosing answers and are sure the answers chosen are correct. Whereas misconception is the wrong answer and/or the reason for choosing the answer is also wrong but you

are sure of the answer. Based on the results of research on student mastery of concepts and misconceptions, it can be seen in Figure 2.
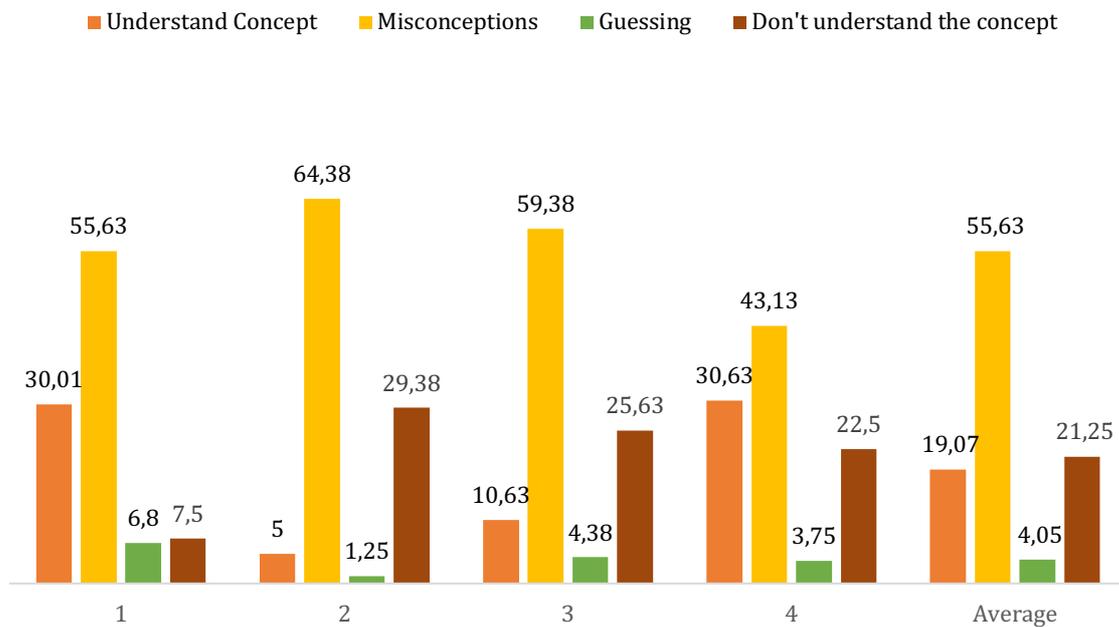
Figure 2. Average Mastery of Concepts and Misconceptions of Students in the Biotechnology Course

Based on Figure 2, it shows that overall only 19.07% of Biology Education FKIP UIR students understand well the biotechnology course, while 55.63% of students still experience misconceptions and 21.25% of students do not understand the concept of biotechnology being taught. Based on the data analysis above, it shows that students of the Biology Education Study Program have different dynamics regarding mastery of concepts in biotechnology courses. The biotechnology course is a compulsory course that must be taken by students in odd semesters with a load of 3 credits. CPMK and the content of this course can be seen in Table 7 below.

Table 7.
CPMK and Study Materials for the Biotechnology Course in the UIR Biology Education Study Program

Learning Outcames	Study Materials
Students are able to master the concepts and principles of medical biotechnology, agriculture, animal husbandry, environment, marine, pharmaceuticals that are relevant for analysis and synthesis in the field of general and special biology	- Linkage of biotechnology with scientific field principles - Development of biotechnology - The role and mechanism of microbial enzymatics in biotechnology
Able to master natural phenomena with a medical biotechnology approach, agriculture, animal husbandry, environment, marine, pharmacy, to predict and provide solutions to problems in the field of biology	- Conventional and modern biotechnology - Cloning of plants and animals and animal stem cells - DNA analysis and application of biotechnology in health and forensics
Students are able and responsible for planning, implementing and evaluating research work in Biotechnology.	- Application of biotechnology in the field of environment and agriculture - Biotechnology safety and ethics - Conventional biotechnology manufacturing practices

In essence the biotechnology lectures at the Biology Education Study Program wich is in Peknbaru city aim to equip prospective biology teacher students in teaching biotechnology material to junior high or high school students (Lecturer, 2020). But on the other hand, as someone who graduated from the Biology Education Study Program, students must be able to master the concept of biotechnology in

depth and be able to apply it in everyday life. Based on CPMK biotechnology, students are expected to be able to master the concepts and principles of biotechnology from various fields, be able to explain the basic concepts of biotechnology and provide examples of biotechnology from various fields and besides that students are also able to design, carry out and evaluate practicum/research work in the field of biotechnology (Yilmaz & Demirhan, 2021; Abuqamar et al., 2015; Casanoves et al., 2015; Surmeli & Sahin, 2010).Mastery of concepts in biotechnology courses can be improved with learning innovations in the classroom in the laboratory (Orhan & Sahin, 2018).

Based on the analysis of the data above, it shows that Biology Education students at FKIP UIR still have difficulty understanding the concept of biotechnology in biotechnology courses taught in the previous semester. Based on Figure 1, it shows that students' mastery of concepts after attending lectures is still in a very low category with a percentage of 19.07% or in other words as many as 6 people who understand the concept while 55.63% or 18 students experience misconceptions and as many as 21.25% (7 people) still do not understand with the concepts that have been taught.

The biotechnology course is a difficult subject to understand because it uses various fields of science as prerequisites (Widiarti et al., 2022) such as anatomy, microbiology, cell biology, physiology, biochemistry and engineering (Goh & Sze, 2019). To facilitate students' mastery of concepts, it is necessary to provide passing prerequisites in the supporting courses. Based on information from the study program that taking courses that have prerequisites must obtain approval from the academic supervisor and the course lecturer is allowed to check the prerequisites needed for the course.

Table 3 show the percentage of student mastery of concepts and misconceptions in indicator 1, namely students understand the basic concepts of biotechnology. In this indicator students will be tested for their mastery of concepts related to the basic concepts of biotechnology related to other subjects such as cell biology, genetics, biochemistry and others. Students' understanding of the prerequisite courses is an important requirement to make it easier for students to understand the basic concepts of biotechnology. From these data it shows that only 10.63% of students understand the basic concepts of biotechnology well, while the rest are still wrong or have misconceptions and even a quarter of students do not understand the they have learned at all. Some of the concepts from different subjects tested are genetics, cell biology and biochemistry. The results show that students still do not understand simple concepts in these basic courses. This may be due to several things such as the materials have been obtained for a long time so that they are forgotten or also because students do not understand them well.

Apart from checking students' knowledge of basic concepts, the second indicator in this study is related to the processes that occur in biotechnology. In the biotechnology course, several concepts as the basis of biotechnology processes include competency, totipotency, fermentation, genetic engineering and recombinant DNA as a product of engineering. Based on Table 4 and Figure 2, it shows that students experience the highest misconceptions on this indicator, namely 64.38% for 32 students. This shows that the concept of biotechnology is very difficult for students to understand. Based on research showing that biotechnology lectures or learning need to be supported by various models, media and learning designs and it is very important to implement laboratory-based practicum activities to strengthen student understanding (Saparuddin et al., 2021; Halimah et al., 2020; Subekti et al., 2020; Orhan & Sahin, 2018; Geng & Alani, 2015).

In Indonesia, learning biotechnology at various levels from junior high school to tertiary institutions certainly contains two main concepts, namely conventional and modern biotechnology. An understanding of conventional biotechnology is very important considering that in Indonesia many food and beverage products from the public use the concept of biotechnology. Besides that, conventional biotechnology lectures and learning are very easy to do both in theory and practicum. Based on interviews with lecturers and students of the Biology Education study program wich is in Pekanbaru city, it shows that biotechnology lecture activities are carried out in two events, namely lectures, discussions and presentations on theoretical activities while practicum activities are carried out on conventional biotechnology material. Whereas modern biotechnology is difficult to carry out practicum activities considering the materials and tools used are not available on campus and the price is very expensive. Tables 5 and 6 show that students' mastery of concepts is still low on both indicators, namely the characteristics of conventional and modern biotechnology and on examples of biotechnology products. The most common misconceptions occurred in indicator 3 of 59.38 and 43.13% in indicator 4. Meanwhile, from the point of view of mastery of concepts, students understood more about examples

of biotechnology products (30.63%) than biotechnology characteristics (10.63%).

Misconceptions are the difference in thinking between the concepts that students have and concepts from scientific theories determined by experts (Eitel et al., 2021); Gurel et al., 2015; Amsel et al., 2011), but believes the answers given are correct (Jago Duda et al., 2020; Mustakim et al., 2015) The definition of biotechnology must be interpreted carefully because if you do not understand the principles of biotechnology well, there will be many misconceptions in this course. Several things that lecturers can do to avoid misconceptions are to first identify the concepts students have before starting lectures and provide assistance during lectures, especially if lectures are peer tutors (group presentation).

Based on the results of research that has been done that in general students' misconceptions are in a fairly high category with a percentage of 55.63%, this means that more than half of students experience misconceptions from biotechnology courses. Of all the indicators that have been measured, the highest misconception is in the second indicator regarding biotechnology processes. In this concept students are tested for their understanding of the concept of totipotency, recombinant DNA competence and other concepts. Most of them understand these concepts but do not understand in detail so that several distractors that have been prepared are selected as answers and they are sure of these answers. These results also indicate that students do not deeply understand the concept being tested. Apart from that, another factor that causes misconceptions is that students do not get meaningful learning during lectures, for example students obtain information using the lecture method instead of experiments (practicum) (Mukhlisa, 2021).

The National Research Council states that misconceptions play a major role in hindering students' learning of science. Students have difficulty in developing the right ideas as the initial foundation for developing further ideas. In addition, teachers can also experience misconceptions in teaching science, be it biology, physics or chemistry, which will have an effect on students' misconceptions. In other words, misconceptions will interfere with the quality and quantity of science learning processes and outcomes for both students and teachers (Soeharto et al., 2019).

CONCLUSION

Students' mastery of concepts in biotechnology courses is in the very low category with a percentage of 19.07%, while 55.63% of students experience misconceptions and 21.25% of students do not understand the concepts they have. For researchers who are interested in conducting research, it is best to provide treatment that is relevant to the characteristics of biotechnology content before testing students' concepts and misconceptions.

ACKNOWLEDGEMENT

REFERENCES

Abuqamar, S., Alshannag, Q., Sartawi, A., & Iratni, R. (2015). Educational awareness of biotechnology issues among undergraduate students at the united arab emirates university. *Biochemistry and Molecular Biology Education*, *43*(4), 283–293. https://doi.org/10.1002/bmb.20863

Amsel, E., Baird, T., & Ashley, A. (2011). Misconceptions and conceptual change in undergraduate students' understanding of psychology as a science. *Psychology Learning and Teaching*, *10*(1), 3–10. https://doi.org/10.2304/plat.2011.10.1.3

Bradshaw, L., & Templin, J. (2014). Combining Item Response Theory and Diagnostic Classification Models: A Psychometric Model for Scaling Ability and Diagnosing Misconceptions. *Psychometrika*, *79*(3), 403–425. https://doi.org/10.1007/s11336-013-9350-4

Casanoves, M., González, Á., Salvadó, Z., Haro, J., & Novo, M. (2015). Knowledge and Attitudes Towards Biotechnology of Elementary Education Preservice Teachers: The first Spanish experience. *International Journal of Science Education*, *37*(17), 2923–2941. https://doi.org/10.1080/09500693.2015.1116718

Creswell, J. (2015). *Educational Research; Planning, Conducting, and Evaluating Quantitative and Qualitative Research, FIFTH EDITION*.

Eitel, A., Prinz, A., Kollmer, J., Niessen, L., Russow, J., Ludäscher, M., Renkl, A., & Lindner, M. A. (2021). The Misconceptions About Multimedia Learning Questionnaire: An Empirical Evaluation Study

With Teachers and Student Teachers. *Psychology Learning and Teaching*, *20*(3), 420–444. https://doi.org/10.1177/14757257211028723

Geng, F., & Alani, F. (2015). Biotechnology labs reinvented through experiential learning: Enhancing student outcomes through the "flipped lab." *Proceedings of the Canadian Engineering Education Association*. https://doi.org/10.24908/pceea.v0i0.5749

Goh, W. W. Bin, & Sze, C. C. (2019). AI Paradigms for Teaching Biotechnology. *Trends in Biotechnology*, *37*(1), 1–5. https://doi.org/10.1016/j.tibtech.2018.09.009

Gurel, D. K., Eryilmaz, A., & McDermott, L. C. (2015). A review and comparison of diagnostic instruments to identify students' misconceptions in science. *Eurasia Journal of Mathematics, Science and Technology Education*, *11*(5), 989–1008. https://doi.org/10.12973/eurasia.2015.1369a

Halimah, M., Rahmat, A., & Redjeki, S. (2020). Biotechnology learning profile biology in FKIP Biology Education Study Program Pasundan University Bandung Indonesia. *Journal of Physics: Conference Series*, *1521*(4). https://doi.org/10.1088/1742-6596/1521/4/042031

Hasan, S., Bagayoko, D., & Kelley, E. L. (2014). *Misconceptions and the Certainty of Response Index (CRI)*. *September 1999*. https://doi.org/10.1088/0031-9120/34/5/304

Hidayah, L. U., Imam Supardi, K., & Woro Sumarni. (2018). Penggunaan Instrumen Lembar Wawancara Pendukung Tes Diagnostik Pendeteksi Miskonsepsi Untuk Analisis Pemahaman Konsep Buffer-Hidrolisis. *Jurnal Inovasi Pendidikan Kimia*, *12*(1), 2075–2085. https://doi.org/10.15294/jipk.v12i1.13299

Hilgartner, S. (2017). *Biotechnology*. *December 2015*, 0–26. https://doi.org/10.1016/B0-08-043076-7/03147-8

Istiyani, R., Muchyidin, A., & Rahardjo, H. (2018). Analisis miskonsepsi siswa pada konsep geometri menggunakan. *Cakrawala Pendidikan*, *37*(2), 223–236. https://media.neliti.com/media/publications/261628-analysis-of-student-misconception-on-geo-bcb7b618.pdf

Jago Duda, H., Esti Wahyuni, F. R., & Edy setyawan, A. (2020). Mengidentifikasi Mengidentifikasi miskonsepsi mahasiswa pendidikan biologi pada konsep Bioteknologi Hewan. *BIOEDUSCIENCE: Jurnal Pendidikan Biologi Dan Sains*, *4*(1), 97–105. https://doi.org/10.29405/j.bes/4197-1054807

Jubaedah, D. S., Kaniawati, I., Suyana, I., Samsudin, A., & Suhendi, E. (2017). *Pengembangan Tes Diagnostik Berformat Four-Tier Untuk Mengidentifikasi Miskonsepsi Siswa Pada Topik Usaha Dan Energi*. *VI*, SNF2017-RND-35-SNF2017-RND-40. https://doi.org/10.21009/03.snf2017.01.rnd.06

Kaplar, M., Lužanin, Z., & Verbić, S. (2021). Evidence of probability misconception in engineering students—why even an inaccurate explanation is better than no explanation. *International Journal of STEM Education*, *8*(1). https://doi.org/10.1186/s40594-021-00279-y

Lestari, A., & Susantini, E. (2020). Pengembangan Instrumen Tes Miskonsepsi Menggunakan Four-Tier Test pada Materi Transpor Membran. *Berkala Ilmiah Pendidikan Biologi (BioEdu)*, *9*(3), 371–377. https://doi.org/10.26740/bioedu.v9n3.p371-377

Lestari, E. A., Harjito, H., Susilaningsih, E., & Wijayati, N. (2021). Analisis Miskonsepsi Menggunakan Tes Diagnosa Three-Tier Multiple Choice Pada Materi Stoikiometri. *Jurnal Inovasi Pendidikan Kimia*, *15*(2), 2824–2830. https://doi.org/10.15294/jipk.v15i2.29171

Mukhlisa, N. (2021). Miskonsepsi Pada Peserta Didik. *SPEED Journal : Journal of Special Education*, *4*(2), 66–76. https://doi.org/10.31537/speed.v4i2.403

Mustakim, T. A., Zulfiani, Z., & Herlanti, Y. (2015). Identifikasi Miskonsepsi Siswa Dengan Menggunakan Metode Certainty of Response Index (Cri) Pada Konsep Fotosintesis Dan Respirasi Tumbuhan. *Edusains*, *6*(2). https://doi.org/10.15408/es.v6i2.1117

Orhan, T. Y., & Sahin, N. (2018). The impact of innovative teaching approaches on biotechnology knowledge and laboratory experiences of science teachers. *Education Sciences*, *8*(4). https://doi.org/10.3390/educsci8040213

Pesman, H., & Eryilmaz, A. (2010). Development of a Three-Tier Test to Assess Misconceptions About Simple Electric Circuits. *The Journal of Education Research*, *103*, 208–222. https://doi.org/10.1080/00220670903383002

Ripoll, V., Godino-Ojer, M., & Calzada, J. (2023). Development of engineering skills in students of biotechnology: Innovation project "From laboratory to industry." *Education for Chemical Engineers*, *43*(October 2022), 37–49. https://doi.org/10.1016/j.ece.2023.01.006

Saparuddin, S., Lestari, U., & Suarsini, E. (2021). Persepsi dan Kebutuhan Mahasiswa Calon Guru Biologi terhadap Media Pembelajaran Bioteknologi. *Jurnal Pendidikan: Teori, Penelitian, Dan Pengembangan*, *6*(5), 720. https://doi.org/10.17977/jptpp.v6i5.14782

Shalihah, A., Mulhayatiah, D., & Alatas, F. (2019). Identifikasi Miskonsepsi Menggunakan Tes Diagnostik Three-Tier Pada Hukum Newton Dan Penerapannya. *Journal of Teaching and Learning Physics*, *1*(1), 24–33. https://doi.org/10.15575/jotalp.v1i1.3438

Smith, J. (2012). *Biotechnology Fifth Edition* (5th ed.). cambridge.org.

Soeharto, Csapó, B., Sarimanah, E., Dewi, F. I., & Sabri, T. (2019). A review of students' common

misconceptions in science and their diagnostic assessment tools. *Jurnal Pendidikan IPA Indonesia*, *8*(2), 247–266. https://doi.org/10.15294/jpii.v8i2.18649

Subekti, H., Susilo, H., Ibrohim, I., Suwono, H., & Purnomo, A. R. (2020). *Exploration of Balai Materia Medica Batu: Field-Trip Supporting Biotechnology Learning*. December. https://doi.org/10.2991/miseic-19.2019.44

Suhandi, A., Sinaga, P., Kaniawati, I., & Suhendi, E. (2008). Efektivitas Penggunaan Media Simulasi Virtual Pada Pendekatan Pembelajaran Konseptual Interaktif Dalam Meningkatkan Pemahaman Konsep Dan Meminimalkan Miskonsepsi. *Jurnal Pengajaran Matematika Dan Ilmu Pengetahuan Alam*, *12*(1), 48. https://doi.org/10.18269/jpmipa.v12i1.317

Surmeli, H., & Sahin, F. (2010). Examination of university students' attitudes towards biotechnological studies in terms of faculty and gender variables. *Procedia - Social and Behavioral Sciences*, *2*(2), 3999–4005. https://doi.org/10.1016/j.sbspro.2010.03.630

Tim dosen. (2020). *Kurikulum Program Studi Pendidikan Biologi Universitas Islam Riau*.

Treagust, D. F. (1988). *Development and use of diagnostic tests to evaluate students ' misconceptions in science Development and use of diagnostic tests to evaluate students' misconceptions in science*. *10*(2), 159–169. https://doi.org/10.1080/0950069880100204

Utomo, A. P., Hasanah, L., Hariyadi, S., Narulita, E., Suratno, & Umamah, N. (2020). The effectiveness of steam-based biotechnology module equipped with flash animation for biology learning in high school. *International Journal of Instruction*, *13*(2), 463–476. https://doi.org/10.29333/iji.2020.13232a

Yilmaz, M., & Demirhan, H. (2021). Variables predicting prospective biology teachers' acceptance perceptions regarding gene technology. *European Journal of Science and Mathematics Education*, *2*(3), 183–192. https://doi.org/10.30935/scimath/9410

Zubaidah, S., & Pangestuti, A. A. (2016). Peta Konsep sebagai Alat Evaluasi pada Pembelajaran Biologi Concept Map as Evaluation Tool in Biology. *Proceeding Biology Eucation Conference*, *13*(1), 164–168. https://media.neliti.com/media/publications/176158-ID-peta-konsep-sebagai-alat-evaluasi-pada-p.pdf