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# Identification of Physics Misconceptions Using Five-tier Diagnostic Test: Newton's Law of Gravitation Context

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**Abstract:** Students' understanding of several topics in physics is still low. The teachers only focus on completing curriculum targets without considering their student's understanding and most of them have misconceptions. The study aimed to identify students' misconceptions of physics concepts using the five-tier diagnostic test. Data was collected once using a descriptive-quantitative method. The research sample consisted of 18 students from one of the high schools in West Sumatra. A total of 17 questions was used to identify students' understanding of Newton's law of gravitation. The results showed that students had misconceptions as follows: gravitational attraction is only caused by planets; there is no gravitational force in space, and the direction of the gravitational force is determined by the direction of the gravitational attraction by some objects; two objects have different gravitational force strengths; all planets revolve around one another, the orbit of the solar system is perfectly circular, the shape of the earth is round, and the strength of the gravitational field is affected by the mass of the object. In conclusion, the highest percentage of misconceptions occurs in the influence of the gravitational field strength, which was 23%.

**Keywords:** Five-tier diagnostic test; Newton's law of gravitation; Physics misconceptions

## Introduction

Physics is one of the sciences that studies natural phenomena that are explained through concepts, theories, laws, and in the form of mathematical equations. Kaniawati and friends explain the meaning of the concept as an idea about a group of objects based on relevant experience, consisting of facts (qualitative) and calculations (quantitative) (Kaniawati et al., 2016). Apart from teachers and printed books, the concept of physics as a science that studies physical phenomena in nature can also take advantage of environmental observations as a source of learning (Hadzigeorgiou, 2021).

Understanding the concept is an important basis or goal in physics learning. Understanding the concept of physics is the ability to accept the definition or meaning of a phenomenon as a result of observing the environment and then explain that meaning into a definition that is better understood by the students themselves (Sarkity et al., 2020). The meanings obtained may or may not be under the actual physics concept. Meanings that are not under the actual concept are known as wrong concepts or misconceptions (Rosita et al., 2020; Yu et al., 2015). According to Fariyani et al. misconceptions occur when students do not provide a correct explanation of the concept of physics by what has been agreed upon by scientists, students build their own theories in their minds which are not necessarily true from everyday experience (Fariyani et al., 2015). The wrong physics concept will remain to stay in student's mind if left unchecked (Handhika et al., 2015).

Many misconceptions occur in physics learning, including in Newton's law of gravitation. Some students believe that the gravitational force is the same as the acceleration of gravity (Syuhendri, 2019). Furthermore, based on observations made at one of high school in West Sumatra regarding the implementation of physics learning on Newton's law of gravitation material, the teacher already used a scientific approach, but when asking and answering the concept of physics and the

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evaluation of daily tests, several students had misconceptions. Following up with the teacher, some students may experience conceptual errors but he has not identified the problems in detail. The average score of students' daily tests on Newton's law of gravity is 39.5 which is lower than the Minimum Completeness Criteria (KKM) of 75. In line with the opinion of Aulia et al. explained that one of the initial causes of low student learning outcomes was due to misconceptions (Aulia et al., 2018).

Misconceptions are problems in learning that do not only affect one material but can transmit these errors to the next related material. Having misconception could lead to the student's achievement in school. This incorrect concept or misconception must be overcome, but the teacher should be aware of misconceptions per sub-concepts. However, teachers rarely give diagnostic tests to detect student misconceptions. They usually use multiple choice without giving attention to the conceptual understanding of student related the topic given. Therefore, one of the instruments that teachers can use to identify this misconception is a diagnostic test (Cakmakci, 2010; Kaltakci-Gurel et al., 2017; Leinonen et al., 2013).

According to Dendodi that the tests that aims to measure the level of knowledge of students' concepts is the diagnostic test, and the findings of this test can help teachers plan solutions to overcome misconceptions (Dendodi et al., 2020). There are several forms of diagnostic tests including one-tier, two-tier, three-tier, four-tier, and five-tier. One-tier is a form of a test consisting of main questions and several answer choices, two-tier consists of one-tier questions with an additional level of confidence in the answers, three-tier consists of two-tier questions with an additional choice of reasons, four-tier consists of three-tier questions with an additional level of confidence in the reason, and then the five-tier consists of four-tier questions completing with a source of information/conclusions (Anam et al., 2019; Putri & Ermawati, 2021). However, the five-tier diagnostic test with multiple choice questions is the most used form of diagnostic test because it has the advantage of having five levels of questions (multi-tier) which serves to reduce the effect of guessing on students, multiple-choice questions are easier for students to answer, scoring is consistent, and does not take up a lot of time (Liu et al., 2011; Rodriguez, 2003; Roediger & Marsh, 2005; Smith & Karpicke, 2014).

Five-tier diagnostic test is one of the tests that are effective in identifying misconceptions. The instrument is not only able to identify the percentage of students who experience misconceptions but also knows the location of the sub-concepts (Bayuni et al., 2018; Putra et al., 2020; Rosita et al., 2020).

**Table 1.** Format of Five-Tier Diagnostic Test Questions

| Tier | Question and Answer Choices |
|---|---|
| Tier-1 | Main question.<br>Answer choices:<br>A. Option1<br>B. Option2<br>C. Option3<br>D. Option4<br>E. Option5 |
| Tier-2 | Confidence Level of Answer<br>□ Sure □ Not Sure |
| Tier-3 | Reason choices:<br>A. Reason Choices 1<br>B. Reason Choices 2<br>C. Reason Choices 3<br>D. Reason Choices 4<br>E. Reason Choices 5<br>F. Reason Choices 6<br>(Students can write their own reason) |
| Tier-4 | Confidence Level of Reason<br>□ Sure □ Not Sure |
| Tier-5 | Essay question |

Therefore, the diagnostic test instrument is important to use in physics learning. The instrument could detect students' misconceptions. The diagnostic test used in this study is a five-tier diagnostic test instrument to reveal students' physics misconceptions about Newton's law of gravitation. The purpose of this study was to identify the misconceptions in Newton's law of gravitation material and to determine the percentage of students who experienced misconceptions in each sub-concept.

## Method

This research is using a quantitative-descriptive method with a non-experimental, which is a form of research in which the subject was not given treatment (Creswell, 2012). The subjects in this research were 18 students in one high school at West Sumatra. Previously, the instrument was validated by experts, which was 97% of questions in the very good category. The instruments were used to get an initial picture of students' misconceptions about Newton's law of gravitation. A total of 17 questions in this material were distributed to the students. The distribution of the sub-concepts is shown in Table 2.

**Table 2.** Distribution of Sub-Concepts

| Indicators | Sub-concept | Number of questions |
|---|---|---|
| Indicator 1 | Gravitational force between particles | 1, 2, 3, 4, 5, 6, 7 |
| Indicator 2 | Gravitational field, gravitational acceleration, gravitational potential energy, and gravitational potential | 8, 9, 10, 11, 12 |
| Indicator 3 | Kepler's Law | 13, 14, 15, 16 |
| Indicator 4 | Acceleration of satellite movement | 17 |

The sample of the question in the five-tier diagnostic test is shown in the Figure 1.

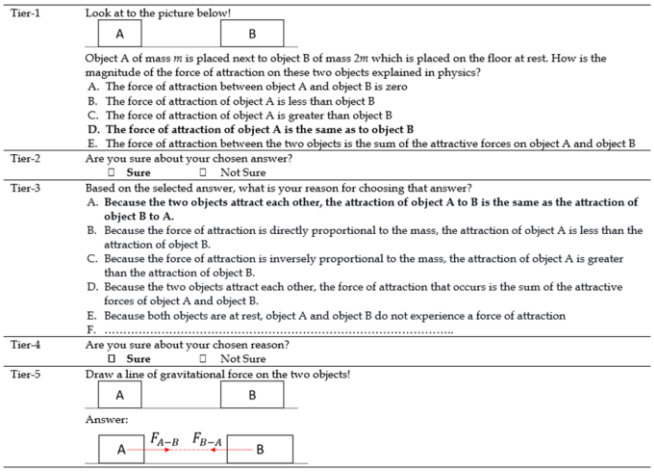


**Figure 1.** Sample of question in the five-tier diagnostic test

The data analysis technique used in describing students' misconceptions is the descriptive technique. The answers obtained from the test results were interpreted using the results interpretation guidelines. Apart from misconceptions, this diagnostic test can also determine other categories of concept understanding, namely Sound Understanding (SU), Partial Understanding (PU), Partial Understanding with Specific Misconception (PUSM), Specific Misconception (SM), and No understanding (NU) (Renner, Abraham, Grzybowski, & Marek, 1992). The interpretation guidelines used in the instrument are shown in Table 3.

Furthermore, the technique used to determine the percentage of students who experience misconceptions according to the formula below.

$$\bar{X} = \frac{\sum X_n}{N} \quad (1)$$

Where $\bar{X}$ = percentage, $X_n$ = students who have misconceptions, $N$ = number of students who take the test.

**Table 3.** Guidelines to Interpret the Result

| Tier-1 | Tier-2 | Tier-3 | Tier-4 | Tier-5 | Categories |
|---|---|---|---|---|---|
| Correct | Sure | Correct | Sure | Accordance | SU |
| | | | | Partially Accordance | PU |
| | | | | Does Not Accordance | PUSM |
| Correct | Not Sure | Correct | Sure | Accordance, partially accordance, or does not accordance | PU |
| Correct | Sure | Incorrect | Sure | | |
| Correct | Sure | Correct | Not Sure | | |
| Incorrect | Sure | Correct | Sure | | |
| Incorrect | Sure | Correct | Not Sure | | |
| Correct | Not Sure | Incorrect | Sure | | |
| Incorrect | Not Sure | Correct | Sure | | |
| Correct | Sure | Incorrect | Not Sure | | |
| Correct | Not Sure | Correct | Not Sure | | |
| Correct | Not Sure | Incorrect | Not Sure | | |
| Incorrect | Not Sure | Correct | Not Sure | | |
| Incorrect | Sure | Incorrect | Not Sure | | |
| Incorrect | Not Sure | Incorrect | Sure | | |
| Incorrect | Sure | Incorrect | Sure | Accordance, partially accordance, or does not accordance | SM |
| Incorrect | Not Sure | Incorrect | Not Sure | Accordance | PU |
| | | | | Partially accordance or does not accordance | NU |

## Result and Discussion

The five-tier diagnostic test consisted of 17 questions in Newton's law of gravitation material. This material is divided into four sub-concepts, namely the gravitational force between particles, the influence of the gravitational field on gravitational acceleration and gravitational potential, Kepler's laws, and the acceleration of satellite movement. The first sub-concept is in questions number 1 to 7, the second sub-concept is in questions number 8 to 12, the third sub-concept is in questions number 13 to 16, and the fourth sub-concept is in question number 17. The results obtained in this study can be seen in Table 4.

**Table 4.** Analysis Results of Students' Understanding Level

| No. Questions | SU (%) | PUSM (%) | PU (%) | SM (%) | NU (%) |
|---|---|---|---|---|---|
| 1 | 28 | 17 | 22 | 28 | 6 |
| 2 | 17 | 0 | 61 | 17 | 6 |
| 3 | 11 | 0 | 50 | 33 | 6 |
| 4 | 0 | 6 | 56 | 17 | 22 |
| 5 | 6 | 22 | 44 | 6 | 22 |
| 6 | 11 | 6 | 33 | 28 | 22 |
| 7 | 6 | 0 | 61 | 17 | 17 |
| 8 | 0 | 0 | 44 | 22 | 33 |
| 9 | 0 | 6 | 78 | 11 | 6 |
| 10 | 11% | 0% | 44% | 28 | 17 |
| 11 | 0% | 6% | 44% | 22 | 28 |
| 12 | 0% | 6% | 28% | 33 | 33 |
| 13 | 17% | 28% | 33% | 6 | 17 |
| 14 | 17% | 17% | 17% | 22 | 28 |
| 15 | 0% | 6% | 56% | 17 | 22 |
| 16 | 0% | 0% | 28% | 28 | 44 |
| 17 | 11% | 0% | 44% | 11 | 33 |
| Average | 8% | 7% | 44% | 20 | 21 |

Based on Table 4, clearly stated that only a few students can understand the concept well or partial understanding with specific misconception, which obtained an average of 8% and 7%, respectively. Furthermore, the highest category owned by students who partially understood the concept, which was obtained an average of 44%. Students who experience misconceptions get an average of 20%, they answered all the questions incorrectly but feel confident in their answers. Students who did not understand the concept obtained an average of 21%, they did not answer correctly in any tier and felt not sure of the answer. The category of SM for each sub-concepts was formed in the Figure 2.

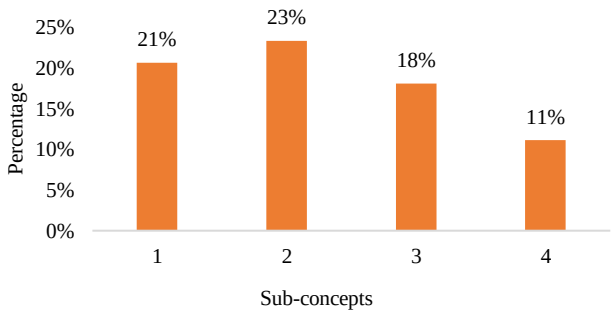


**Figure 2.** SM for each sub-concept

Based on the graph in Figure 2, it was stated that the misconceptions in sub-concept 1 are 21%, sub-concept 2 is 23%, sub-concept 3 is 18%, and sub-concept 4 is 11%. The highest misconception occurs in sub-concept 2, regarding the influence of the gravitational field strength on gravitational acceleration and gravitational potential. One sample of students' misconception answers can be seen in Table 5.

**Table 5.** Students' Response in Answering Question Number 1 (SM Category)

| Tier | Question and Student Answer | Interpretation Answer |
|---|---|---|
| Tier-1 | The gravitational field is the space around an object with mass (stationary object) which if placed another mass object as a test object in the space will experience the force of gravity. However, how about the magnitude of the gravitational field of a stationary object if the test object is removed?<br>A. The gravitational field of a stationary object will also disappear<br>B. The gravitational field of a stationary object will remain the same<br>C. The gravitational field of a stationary object will weaken<br>D. The gravitational field of a stationary object will strengthen<br>E. The gravitational field of a stationary object will move<br>Student response: *C* | Incorrect Answer |
| Tier-2 | Are you sure about your chosen answer?<br>□ Sure □ Not Sure<br>Student response: *Sure* | Sure |
| Tier-3 | Based on the selected answer, what is your reason for choosing that answer?<br>A. The gravitational field is not affected by the test object, so if the test object is removed, the gravitational field of the object at rest will remain the same.<br>B. The gravitational field is affected by the test object, so if the test object is removed, the gravitational field of the stationary object will also disappear. | Incorrect Answer |

| Tier | Question and Student Answer | Interpretation Answer |
|---|---|---|
| | C. The gravitational field is strengthened by the test object, so if the test object is removed, the gravitational field of the stationary object will weaken.<br>D. The gravitational field is absorbed by the test object, so if the test object is removed, the gravitational field of the stationary object will strengthen.<br>E. The gravitational field is absorbed by the test object, so if the test object is removed, the gravitational field of the stationary object will move to the test object.<br>F. ……... | |
| | Student response: *C* | |
| Tier-4 | Are you sure about your chosen reason?<br>□ Sure □ Not Sure | Sure |
| | Student response: *Sure* | |
| Tier-5 | Explain the factors that cause the existence of a gravitational field on an object?<br>Answer:<br>Student response: *The test object.* | Does not accordance |

The question illustrated a test object placed around a stationary object. Students were asked to determine the change in the strength of the gravitational field of a stationary object if the test object is removed. Based on Table 6, it can be seen that students believe the loss of the test object will weaken the strength of the gravitational field of a stationary object. Whereas the actual concept is that the field strength is only influenced by the mass of a stationary object so that the presence or absence of a test object will not affect the strength of the gravitational field of a stationary object (Halliday, Resnick, & Bowen, 2014). The strength of the gravitational field of a stationary object will remain constant as long as the mass of the stationary object was also constant. It can be seen that students were answered "*sure*" for both tier-2 and tier-4. However, the students said that the test object is one of the factors causing the existence of a gravitational field of an object (tier-5). This series of student answers were included in the category of SM because students feel surely with their answers even though the answers given were incorrect and not suitable with the actual knowledge.

Apart from students' answers as shown in Table 6, there were also variants of other student answers that fall into the category of SM. The absence of a test object will eliminate and weaken the strength of the gravitational field of a stationary object. A recapitulation of student answers was shown in Figure 3.

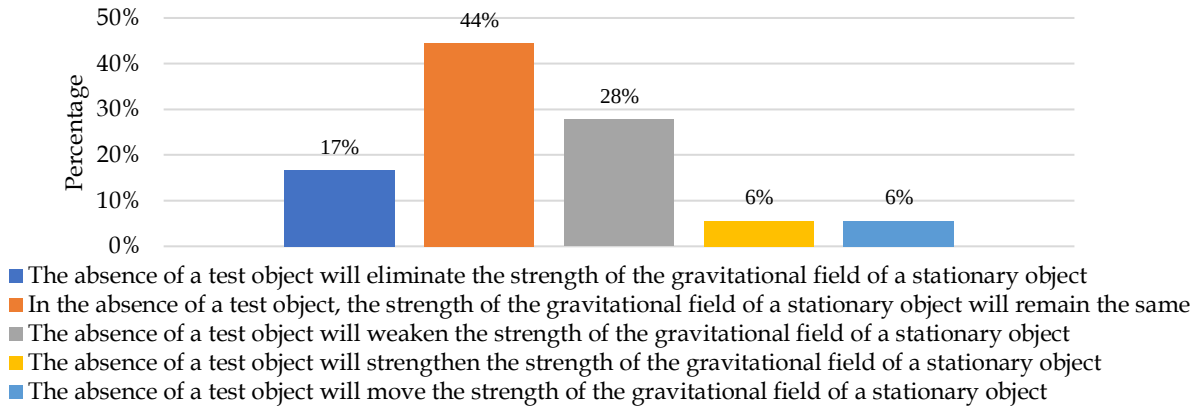


**Figure 3.** Recapitulation of students' responses in answering question number 1

Based on the graph in Figure 3, it was obtained that most students at 44% answered correctly, that the absence of a test object would not affect the strength of the gravitational field of a stationary object. However, among the 44%, no one really understands the concept because students are only correct when answering tier-1 and tier-3, but they answered the tier-5 incorrectly. It indicated that the students have partial knowledge and found it difficult to connect between concepts (Meyer, 2004). In addition, as many as 17% of students answered that the absence of a test object will also eliminate the gravitational field strength of the stationary object, as much as 28% answered that the absence of a test object will also weaken the gravitational field strength of the stationary object, as much as 6% answered that the absence of a test object will also strengthen the gravitational field strength of the stationary object, and as many as 6% answered that the absence of a test object

will also transfer the gravitational field strength of the stationary object to another object. Based on the answer in each option indicated that student understanding of strength gravitational field was lack (Low & Kate, 2017). The level of student understanding in more detail can be seen in Figure 4.

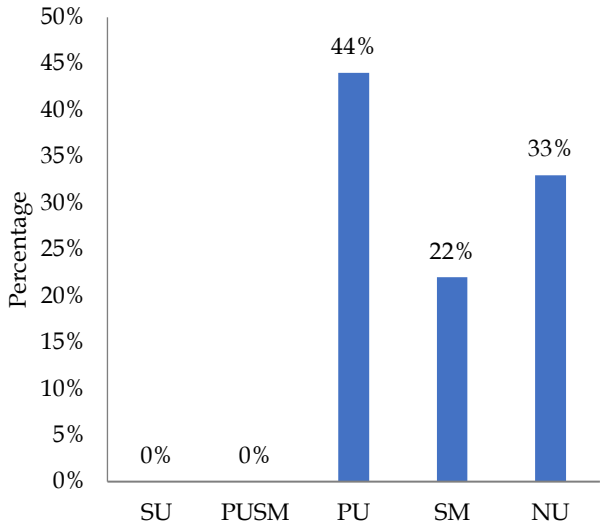


**Figure 4.** Student understanding level in question 1

Based on the graph in Figure 3, it was obtained that 44% of students who answered correctly in Figure 2 were previously included in the category of PU because students were only correct in part of the tier while tier-5 did not match the actual concept. As many as 22% of students experienced SM because they believe in the incorrect answers at all tiers. As many as 33% of students experienced NU because they were not sure and were not correct in any of the tiers.

A similar misconception is also found in one of the questions in sub-concept 2. The question presents an illustration of the Moon experiencing a strong gravitational field emitted by the Earth. Students are asked to determine the change in the strength of the Earth's gravitational field if the Moon's mass is reduced to half of its previous mass. Samples of student answers can be seen in Table 6.

**Table 6.** Misconceptions Sample (Students' Response in Answering Question Number 2)

| Tier | Question and Student' Answer | Interpretation Answer |
|---|---|---|
| Tier-1 | Under ideal conditions, the Moon experiences a strong gravitational field by the Earth as *g*. How would the gravitational field strength change if the Moon's mass was reduced to half of its previous mass while the size remained the same?<br>A. The magnitude of the Earth's gravitational field will be one quarter from the previous.<br>B. The magnitude of the Earth's gravitational field will be fourfold from the previous.<br>C. The magnitude of the Earth's gravitational field will be remains the same as the previous.<br>D. The magnitude of the Earth's gravitational field will be half from the previous.<br>E. The magnitude of the Earth's gravitational field will be double from the previous.<br>Student response: *D* | Incorrect Answer |
| Tier-2 | Are you sure about your chosen answer?<br>□ Sure □ Not Sure<br>Student response: *Sure* | Sure |
| Tier-3 | Based on the selected answer, what is your reason for choosing that answer?<br>A. The strength of the Earth's gravitational field is directly proportional to the square of the mass of the Moon and the mass of the Earth, so if the Moon's mass was reduced by half, the Earth's gravitational field strength will be quarter.<br>B. The strength of the Earth's gravitational field is inversely proportional to the square of the mass of the Moon and the mass of the Earth, so if the Moon's mass was reduced, the Earth's gravitational field strength will be quadrupled.<br>C. The strength of the Earth's gravitational field is directly proportional to the mass of the Earth, so if the Moon's mass was reduced, the Earth's gravitational field strength will not be affected and will remain the same.<br>D. The strength of the Earth's gravitational field is directly proportional to the mass of the Moon and the mass of the Earth, so if the Moon's mass is reduced by half, the Earth's gravitational field strength will also be half.<br>E. The strength of the Earth's gravitational field is inversely proportional to the mass of the Moon and the mass of the Earth, so if the Moon's mass is reduced by half, the Earth's gravitational field strength will be doubled.<br>F. ……<br>Student response: D | Incorrect Answer |

| Tier | Question and Student' Answer | Interpretation Answer |
|---|---|---|
| Tier-4 | Are you sure about your chosen reason?<br>□ Sure □ Not Sure<br>Student response: *Sure* | Sure |
| Tier-5 | Explain the relationship between mass and gravitational field strength!<br>Answer:<br>Student response: *The mass of the Moon and the Earth is directly proportional to the gravitational field.* | Partial accordance |

The concept is the same as in the previous question that the Moon as a test object does not affect the strength of the Earth's gravitational field as a stationary object. The strength of the Earth's gravitational field remains the same if the mass of the Earth also remains the same. In Table 6, students believe the strength of the Earth's gravitational field also decreases by half as the Moon's mass decreases by half. At tier-3 and tier-5 students also believe that the mass of the Moon is directly proportional to the strength of the Earth's gravitational field. This series of student answers is included in misconceptions category because all students' answers are incorrect but students feel sure they are correct. Apart from this answer, there are also other answer variants, namely the strength of the Earth's gravitational field becomes a quarter, same, and becomes half. Variants of answers given by students can be described in the graph in Figure 5.

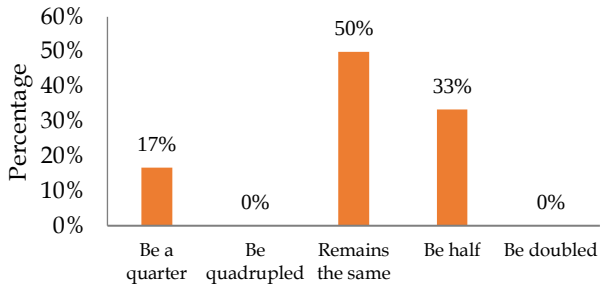


**Figure 5.** Recapitulation of students' responses in answering tier-3 question number 2

Based on the graph in Figure 5, it is known that as many as 50% of students have answered correctly on tier-1 and tier-3, namely the strength of the gravitational field remains the same with reason the mass of the Moon does not affect the strength of the Earth's gravitational field. Furthermore, students who answered incorrectly on tier-1 and tier-3 were obtained as much as 17% namely answering the gravitational field strength to a quarter and 33% answering the gravitational field strength being half with reason the mass of the Moon is directly proportional to the strength of the Earth's gravitational field. The level of student understanding in more detail can be seen in the graph in Figure 6.

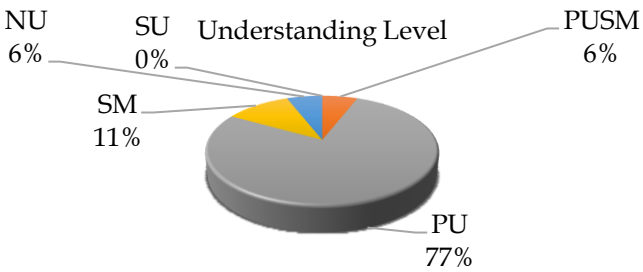


**Figure 6.** Student understanding level in question 2

Based on the graph in Figure 6, it is known that there are no students who really understand the concept well, because students answered correctly on tier-1 and tier-3 but did not accordance on tier-5. In addition, it was found that 6% of students have partial understanding with specific misconception because it was partly appropriate answer at tier-5. As many as 78% of students do partial understand the concept because it is only correct in each one tier. As many as 11% experienced misconceptions because none of the answers given by students were correct but students believed that the answers were correct. As many as 6% of students also do not understand the concept because students are not sure and none of the answers are correct.

**Table 7.** Description of Student's Overall Misconception

| No. | Misconceptions |
|---|---|
| 1. | The gravitational attraction is only caused by objects equivalent to the planets |
| 2. | Size affects the center of mass distance between two objects |
| 3. | There is no gravitational force in space |
| 4. | The direction of the gravitational attraction is in the direction of the resultant force, not towards the center of mass of each object |
| 5. | The direction of the gravitational attraction is in the direction of the motion of the object, not towards the center of the Earth |
| 6. | Two objects that are experience the gravitational attraction have different gravitational attractions |
| 7. | The strength of the gravitational field is affected by the test object |

| No. | Misconceptions |
|---|---|
| 8. | Distance is equal to the square of the distance |
| 9. | Potential energy is equal to gravitational potential |
| 10. | All the planets revolve around each other |
| 11. | The orbit of the solar system is a perfect circle |
| 12. | The shape of the Earth is perfectly round |
| 13. | The speed of the satellite is affected by the distance from the satellite to the Earth's surface. |

From the questions given above, it can be seen that the type of questions was designed to measure the cognitive domain at the level C2 (explanation) where the students are required to explain the concept of gravitational field. Student's misconception about gravitational field due to difficulty in connecting between concept (Gardner, Greeno, Reif, Schoendeld, & Stage, 2009). According to Ausubel's theory, student will have a meaningful learning if they attempt to make sense of new material by linking it to what they already know (Ozdem & Bilican, 2020). According to Bruner's cognitive development theory, the ability to connect a new things with prior knowledge in students' brain include in the transformation stage (Ozdem & Bilican, 2020). As a result, when students fail to reach the transformation stage in their cognitive processes, they may develop misconceptions (Rehalat, 2014).

Based on the two examples of misconceptions presented, misconceptions are obtained in all material questions about Newton's law of gravity, which are as shown in Table 7. There are 13 misconceptions gets. Students experience misconceptions about Newton's Law of gravity, that is the most misconceptions appeared are about the gravitational field concept.

## Conclusion

Based on the results of the research that has been done, misconceptions occur in every question and every sub-concept. The misconceptions obtained in Newton's law of gravity include that the gravitational attraction is only caused by the planets, the size affects the distance of the center of two mass objects, there is no gravitational force in space, the direction of the gravitational attraction by some objects is in the direction of the resultant force, the direction of the force Earth's gravitational attraction is in the direction of the object's motion, two objects that experience gravitational attraction have different gravitational magnitude, the strength of the gravitational field is affected by the mass of the test object, the term distance is equal to the square of the distance, gravitational potential energy is equal to gravitational potential, all planets are mutually around each other, the orbit of the solar system is perfectly circular, the shape of the earth is perfectly round, the speed of the satellite is affected by the distance of the satellite-earth's surface. The highest percentage of misconceptions on Newton's law of gravity occurs in the influence of gravitational field strength on potential energy and gravitational potential sub-concept which was 23%. The results of this study concluded that the five-tier diagnostic test instrument developed was able to identify students' physics misconceptions and help teachers in diagnosing students' understanding of physics concepts.

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There is no conflict of interest.

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