Misconception profile of students in senior high school iv Sidoarjo East Java in work and energy concepts and the causes evaluated using Four-Tier Diagnostic Test

F U Ermawati¹, S Anggrayni¹ and L Isfara¹

¹Physics Department, Faculty of Mathematics and Natural Sciences, Universitas Negeri Surabaya, Surabaya 60231, Indonesia

Abstract. The main issue faced by students in secondary high schools in Indonesia is the difficulties in understanding physics concepts. These difficulties are often caused by a conflict between preconceptions and academic knowledge obtained from school. For example, students’ preconceptions says that Work is an effort by exerting energy and thought. In physics, Work is the dot product between force and displacement vectors whose value is determined by the angle between those vectors. This conflict phenomenon is assured to produce misconceptions. This present study aims to analyse the 10th grade students’ misconception profile in Senior High School IV Sidoarjo East Java on Work and Energy concepts and to identify the sources examined using the developed four-tier multiple-choice test. A total of 30 students participated in this study. The data collection instrument contains 25 physics-concepts questions. Serious misconceptions was identified on Work, Energy Change and Mechanical Energy Conservation concepts as a result of preconceptions. Meanwhile, the similar misconceptions found on Power concept was due to incomplete reasoning.

1. Introduction
In everyday life we witness events such as porters on traditional markets that carry sacks of fruits or vegetables that are taken down from trucks and taken to merchant stalls for sale, or traders who walk along the village while peddling satay placed above his head. These two examples of events contain the concepts of physics, namely Work and Energy. Students assumed that porters carrying goods in the traditional market and also traders who go around the village to offer the satay both do work because they have been sweating and look very tired.

According to the Physics concept, Work (W) is a multiplication of dot product between force and displacement vectors, \( W = F \cdot S = | F| |S| \cos \theta \) [1]. If a system has a total force and displacement, the work carried out by the system depends only on the angle \( \theta \) between the two vectors. For the above events, since the force of load and the displacement are perpendicular (\( \theta = 90^\circ \)), the work that the porters and the merchants do is zero (Cosines 90° = 0). In other words, according to the Physics concept, both the porters and the satay trader are doing nothing, even though they have been sweating and looked very tired. The students’ understanding gathered from various events in everyday life is called initial knowledge (preconceptions) and it turns out that it often creates misconceptions. Misconceptions can affect students’ understanding of the following concepts [2]. Therefore misconceptions must be prevented by being detected. The most suitable misconception diagnostic test applied to a large number of students is a four-tier multiple choice diagnostic test. The first tier is answer choices, the second tier is the level of confidence in the answer chosen, the third tier is the answer reason and the last tier indicates the level of confidence in the reason for the answer chosen [3]–[5]. Students are said to understand the concept (scientific conception) when the answers and reasons are correct and they are very confident in the answers and reasons. Partial understanding is
when the answers and reasons are correct, but the students are not sure of any of the answers or reasons. False positive (lack of knowledge – guessing) is defined when the answer is correct and the reason is wrong, but they are sure of the answer and reason. False negative (also lack of knowledge – guessing) is a condition that is the opposite of false positives. Do not understand the concept (lack of knowledge – deficiency) if both the answers and reasons are wrong and they are not sure of the answers and reasons. Misconceptions is defined when the answers and reasons are wrong but they are confident in the answers and reasons [4], [5]. In addition to preconceptions, there are also some other causes of misconceptions originating from the students themselves, namely: associative thinking, humanistic thinking, incomplete or wrong reasoning and wrong intuition [6]. This paper is intended to identify the profile of misconception of 10th grade students in Senior High School 4 Sidoarjo East Java in Work and Energy concepts based on the causes that originate from themselves using the developed four-tier multiple choice diagnostic test.

2. Method

2.1 Sample

The subject of this study was 10th grade students of Science class at Senior High School 4 Sidoarjo East Java because they learnt Work and Energy concepts from the previous semester. Thirty of them were selected randomly as the sample of this work and whose misconceptions and the causes are planned to identify. Two other group of students were also selected from the target population: the first group was needed for interviews while the second group was hired to complete open-ended test.

2.2. Instrument

The four-tier work and energy diagnostic test was developed step-by-step before being launched. First, searching related literatures to identify potential misconceptions and discussed the results with one physics educator and two physics teachers. Second, conducting semi-structured interviews with some 10th grade students based on their gender (boys and girls) and knowledge level (high-medium-low) from two different schools to collect information on the difficulties and misconceptions faced by the students that do not appear in the literature. The interviews results explain that the students had alternative conceptions, some reported in the literature and some did not. Third, based on the interview findings, open-ended questions consisting of Work and Energy concepts were developed. To check the content validity and reliability of the questions, two physics education experts analysed the appropriateness of the questions to senior high school students’ level. The open-ended questions were tested to other high school students in order to collect students’ responses. The responses were analysed and categorised to create distractors of four-tier test. The meaningful responses and that appear frequently were selected as distractors. These distractors consist of one correct option and three alternative conception options. At last, 25 four-tier questions were constructed; the first tier is the conventional multiple choice answers, the second tier is the confidence level of the answer on the first tier, the third tier is the possible reasons of given answers on the first tier. The reason options were selected based on the five types of causes of misconceptions that originate from the students themselves, namely preconception (PRE), associative thinking (AST), humanistic thinking (HUT), incomplete or wrong reasoning (WOR) and wrong intuition (WOI). By this way, possible causes of students’ misconceptions can be detected easily. The fourth tier is the confidence level of the reasons on the third tier. Table 1 shows a sample of the four-tier questions on Work and Energy concepts developed in this work. The total numbers of questions is 25 covering Work concept (Work), Energy Change concept (E.Change), Conservation of Mechanical Energy concept (CME) and Power concept (Power).The reasons options a, c, d, e and f on the third tier in Table 1 contain alternative reasons, each representing preconceptions, associative thinking, incomplete/wrong reasoning, humanistic thinking and wrong intuition. The b option is the correct reason.
Table 1: A sample of four tier question on Work and Energy concepts developed in this work

| Tiers          | A sample of question                                                                 |
|----------------|-------------------------------------------------------------------------------------|
| First tier     | During the 2018 Asian Games event, an Indonesian weightlifting athlete, Eko Yuli Irawan, won a gold medal. At that time Eko Yuli was able to lift the barbell to a height of 187 cm above the floor. If the mass of the barbell is 50 kg, then Eko's work is equal to ... |
| a.             | 935 J                                                                               |
| b.             | -935 J                                                                              |
| c.             | 9,35 kJ                                                                             |
| d.             | -9,35 kJ                                                                            |
| e.             | Zero                                                                                |
| Second tier    | Are you sure of your answer?                                                        |
| a.             | I am sure                                                                           |
| b.             | I am not sure                                                                       |
| Third tier     | Which one of the following is the reason of your answer?                            |
| a.             | The work exerted by Eko Yuli to lift the barbell is a form of potential energy.      |
| b.             | The intended work against the gravitational force so the angle between the direction of the lifting force and the direction of displacement is 180 ° and \( \cos 180° = -1 \). |
| c.             | When the barbell moves up, the exerted work is positive because the altitude increases. Whereas when the barbell moves down, the work is negative because the altitude decreases. |
| d.             | The direction of force carried out by Eko Yuli is parallel to the direction of displacement so the angle = 0 ° and \( \cos 0° = 1 \). |
| e.             | When the barbell moves up, Eko Yuli's energy decreases so that the exerted work is negative. |
| f.             | The force exerted by Eko Yuli to barbells opposes the gravitational forces so that Eko's work must be positive to overcome the gravitational force. |
| Four tier      | Are you sure of the reason of your answer?                                          |
| a.             | I am sure                                                                           |
| b.             | I am not sure                                                                       |

2.3. Data analysis
In Table 1, each question had one correct answer and one correct reason. The rest options contained alternative conceptions. Due to that, students’ responses were analysed based on these alternative conceptions. Considering there are four levels of students’ response to each question, there are four variables used to analyse the data, namely: a) first tier scores, b) first and third tier scores, c) first and second tier scores, and d) second and forth tier scores. The Cronbach alpha reliability was calculated for the first and third tier scores. A score of 1 is given for correct answers, as well as for the correct reasons. A zero score is given when the answer is wrong, as well as for the wrong reason. The relationship between the first and third tier scores and the confidence tiers was investigated using the coefficient of Pearson product-moment correlation.

The students’ responses were grouped into six categories by modifying Anggrayni and Ermawati results [7]. The intended six categories are as follows: a) understand the concept/scientific conception (UD) when the answers and reasons are correct and the students are very confident in the answers and reasons; b) partial understanding (PR) is when the answers and reasons are correct, but the students are not sure of any of the answers or reasons; c) false positive/lack of knowledge - guessing (FP) is defined when the answer is correct and the reason is wrong, but they are sure of the answer and reason; d) false negative/lack of knowledge - guessing (FN) is a condition that is the opposite of false positives; e) do not understand the concept/lack of knowledge – deficiency (DO) if both the answers and reasons are wrong and they are not sure of the answers and reasons; f) misconceptions (MS) is when the answers and reasons are wrong but they are confident in the answers and reasons.

3. Result and Discussion
The Cronbach alpha reliability index for the first and third tier scores is 0.698, while the reference r-index in the Pearson product moment correlation for total students of 50 and a significant level of 5 % is 0.279 [7]. Since the experimental index is much greater than the reference one, the developed instrument is therefore reliable.
Figure 1 shows the conceptions distribution of 30 students in 10th grade of Science class in Senior High School 4 Sidoarjo East Java in various sub-concepts in Work and Energy concepts, i.e., Work concept, Energy Change concept (E. Change), Conservation of Mechanical Energy concept (CME) and Power concept (Power). As depicted, about 50 % of the students underwent misconceptions when they solved the problems on Work, E. Change, and CME concepts. Only less than 10 % really understood the three concepts. Another less than 10 % understood the concepts partially. Meanwhile, the total proportion for lack of knowledge (guessing), both for false positive and false negative categories, are less than 15 %, except for the CME concept which is more than 20 %. Different phenomenon was recorded on the Power concept, i.e., most of the students (65 %) understood the concept well. Only 7 % of them suffered misconceptions, another 15 % understood partially and about 10 % are guessing. This phenomenon seems to be interesting and therefore is going to be explored further in the following paragraphs.

As mentioned by Suparno in [6], 8 of 10 students in Indonesia faced difficulties to understand physics concepts. Students tend to prefer memorizing formulas rather than understanding a concept so that when students are asked to solve conceptual questions, they find it difficult. Another case is when the questions are in the form of calculations that rely only on the ability to memorise the formulas, students are able to solve the intended questions easily. The questions about Work, E. Change and CME that were tested to the students on the four-tier diagnostic test are conceptual problems. Those questions required students’ understanding on the concepts. For example, first – Question No. 4 is about the concept of Work: “Given a phenomenon of three children going to school, each carrying a backpack with a different weight, students can decide who should make the biggest work to hold the backpack and determine the value of the largest work”. Students generally understood the concept of work based solely on the formula, i.e. work is the multiplication of force and distance, without understanding that the intended force and the intended displacement are vector quantities. A vector quantity does not only have a value, but a vector also has a direction. In other words, students had ignored that the work made by the above children is a dot product between the force and the displacement vectors whose value is determined by the product of the force value, the displacement value and the angle between the two vectors. In this case, the force carried by the shoulders of the
three children leads vertically. At the same time the movement of the children goes forward (horizontal direction), which means that the angle between the force exerted by the shoulder and the children movement displacement is 90°. In other words, the amount of work taken by each child is zero.

Second – Question No. 7 is about the concept of E. Change: “Given a phenomenon of an object with mass m being stationary, then given the force F so that the object moves at a distance s. Students are asked to determine the speed of the object at the distance s”. Students assumed that the speed of an object is only determined by multiplication between the force exerted and the distance. The correct concept says that the work exerted by the intended object is the difference between the kinetic energy at distance s and at the original position, so that the velocity of an object at distance s can be determined by the ratio of the square root of the work and the mass of the object. Third – Question No. 20 is about the concept of CME: “Given a phenomenon of a bullet being fired so as to form a parabolic trajectory. Students can determine the positions where the potential energy and kinetic energy reach the maximum”. Students assumed that at the highest position, the bullet is stationary so that the bullet has no kinetic energy and all the energy possessed by the bullet is in the form of potential energy. The correct concept says that at the highest position, the bullet is not stationary because there is still a velocity component in the horizontal direction, while the velocity in the vertical direction is zero. Thus at the highest position, the bullet has potential energy as well as kinetic energy, where the potential energy reaches its maximum value because of its highest position to the surface of the ground. The total between the kinetic energy and the potential energy along the bullet trajectory path are all the same.

On the other hand, the concept of Power only contains applications of the equation \( P = \frac{W}{t} \) in everyday life; in this case, P, W and \( \Delta t \) each denotes power, work and the time interval during which the work occurs. For students who understood this formula, they had no difficulties to solve the questions. For example, Question No. 24, “given a question on an elevator that moves from the ground floor to floors 1, 2, 3 and 4 at a constant speed of 2 m s\(^{-1}\). The distance between the nearest floors is 7 meters, the rope tension of the elevator is 103 N and there is no friction between the elevator and the wall. Students were asked to determine the displacement of the elevator from certain floor to another floor that requires the most power from the elevator motor”. The result showed that 65 % of the total students answered this question and some other questions on the Power concept correctly. The chosen reasons are also correct; only 6 % experienced misconceptions, 8 % are guessing and 15 % are partial understood, as shown in Figure. 1.

Figure 2 depicts the distribution of students’ misconceptions in various sub-concepts in Work and Energy concepts based on various causes, i.e. preconceptions (PRE), associativistic thinking (AST), incomplete/wrong reason (WOR), humanistic thinking (HUT) and wrong intuition (WOI). As shown, almost 50 % of the misconceptions on the first three sub-concepts are due to preconceptions. The examples of the intended preconceptions are as provided in Table 1 and on the Questions #4, #7 and #20. The AST contributes 15 – 29 %, the HUT is 5 – 30 %, the WOI is 18 %, but for the E. change concept, the WOI cause is 0 %. Meanwhile the PRE cause on the Power concept is only 12%, just as much as the cause of WOI. The dominant cause of 25 % is due to WOR. The AST and HUT causes are none. The examples of misconceptions causes due to AST, WOR, HUT and WOI are as given in Table 1 (the reasons option a, c, d, e and f). Misconceptions caused by preconception are very difficult to overcome because the wrong concept has been deeply embedded in students’ minds. The only way to reduce the wrong preconceptions is to provide empirical and authentic new experiences about the correct concepts to students. In this case, under guidance of a physics teacher, students are asked to do new activities or experiences by involving their senses; these activities should be different from their preconceptions and the students do that activities frequently. If these empirical experiences succeed in instilling new understanding to students, the students’ preconceptions will naturally change by themselves. The similar approaches are also useful to overcome the other misconceptions due to AST, WOR, HUT and WOI.
4. Conclusion

The study to determine the profile of misconceptions on 10th grade students in Science class at Senior High School 4 Sidoarjo, East Java for the concept of Work and Energy, along with identification of the causes of misconception has been completed. The findings confirm the previous results, i.e., the majority of 10th grade students in Science class at Senior High School 4 Sidoarjo East Java did suffer misconceptions which were generally caused by a wrong initial understanding on Physics concepts. With this fact, it is the responsibility of Physics teachers to take concrete actions to reduce the misconception.

References

[1] R. A. Young, H.D.; Freedman, University Physics with Modern Physics.
[2] R. Driver, “Students' conceptions and the learning of science,” Int. J. Sci. Educ., vol. 11, no. 5, pp. 481–490, 1989.
[3] I. S. Caleon and R. Subramaniam, “Do Students Know What They Know and What They Don’t Know? Using a Four-Tier Diagnostic Test to Assess the Nature of Students’ Alternative Conceptions,” Res. Sci. Educ., vol. 40, no. 3, pp. 313–337, 2010.
[4] Z. D. Kirbulut and O. Geban, “Using Three-Tier Diagnostic Test to Assess Students’ Misconceptions of States of Matter,” Eurasia J. Math. Sci. Technol. Educ., vol. 10, no. 5, pp. 509–521, 2014.
[5] D. Kaltakci-Gurel, A. Eryilmaz, and L. C. McDermott, “Identifying pre-service physics teachers’ misconceptions and conceptual difficulties about geometrical optics,” Eur. J. Phys., vol. 37, no. 4, p. 45705, 2016.
[6] P. Suparno, Miskonsepsi dan Perubahan Konsep dalam Pendidikan Fisika. PT Grasindo, 2013.
[7] S. Anggrayni and F. U. Ermawati, “The validity of Four-Tier’s misconception diagnostic test for Work and Energy concepts,” J. Phys. Conf. Ser., vol. 1171, no. 1, 2019.