

Using four-tier diagnostic test instruments to detect physics teacher candidates' misconceptions: Case of mechanical wave concepts

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Abstract. This research purposes to detect misconceptions of physics teacher candidates in Yogyakarta on the topic of mechanical waves. This research uses descriptive analysis method. The sample consisted of 35 physics education students in Yogyakarta. Data collection used a four-tier diagnostic instrument (4WADI) developed by Caleon and Subramaniam. The descriptive analysis findings from this research stated the results of a four-tier diagnostic analysis test classifying students in five categories, including scientific conception, lack of knowledge, false positive, false negative and misconception. Based on the results, the percentage of physics education students' misconceptions in Yogyakarta varies on each problem indicator. The biggest misconception occurred in general characteristics of waves and wave motion represented in the graph by 32.4% and by 30.0% misconceptions on the topics of wave frequency, waves source, and medium properties. In addition, student misconceptions on each sub-topic of mechanical waves are highly categorized and need specific attention to carry out remediation. This finding might be used as a reference for lecturers or teachers to consider sub-topics of mechanical waves that have a high potential for misconceptions. Therefore, lecturers and teachers can apply efficient and effective learning methods and strategies to eliminate students' misconceptions.

Keywords: *misconception, four-tier, diagnostic instruments, mechanical wave concepts*

1. Introduction

Education is a process of developing human resources that supports the advancement of a nation. The success of education facing the era of the industrial revolution 4.0 is determined by the quality of teachers or teacher candidates. Teachers have a strategic role in developing students' potential and constructing the national character [1]. Qualifications and competencies of qualified teachers are important requirements that have to be fulfilled. One of the teachers' competencies is educational competence. This competency requires the teachers to have critical thinking skills, problem-solving abilities, and understanding scientific conceptions so that in learning the teachers can export these competencies to students. Not rarely the conceptual understanding received by students often experiences conceptual differences with scientific facts.

Different terms often appear to represent students' understanding of concepts that are inconsistent with the facts. Some terms mention "conceptual difficulties", "mental models", "phenomenological primitives", "naive beliefs", "misconceptions", and "alternative conceptions" [2]. Whatever term is used



to explain the conceptual differences, the most important thing is how to investigate the concept differences. This research uses the term “misconception” because of the use of familiar terms.

Misconception is a concept developed by students about the scientific process which seems to be supported by a reasonable opinion with beliefs that conflict with the principles, beliefs, and theories of scientists [3]. Students’ knowledge is constructed by the experience of the students themselves. The construction process is obtained through interactions with objects, phenomena, accurate information sources and the students’ environment. If aspects that construct students’ knowledge provide experience and information that is different from scientific understanding, it is likely to cause misconceptions on students. Aspects that can cause misconceptions are the students’ own physics experience, reference books, teachers and the learning methods used by lecturers in the classroom [4]-[6]. The things become the facts of misconception are misconceptions that are sometimes regression in nature, which means that sometime later misconceptions will appear on the same physics topic. Misconceptions can occur at all education grade, even misconceptions can be experienced by students, teachers, or lecturers. Identifying a respondent’s misconception on the physics topic requires specific test instruments. Misconceptions cannot be eliminated by the speech method only, but exact remediation treatment can reduce or eliminate misconceptions [7].

Physics is a fundamental science that discusses natural phenomena by understanding various concepts of the occurrence of these phenomena. Many researchers have investigated students’ conceptions of various phenomena. It was noted that students’ conceptions sometimes were not consistent with correct scientific knowledge. Some physics courses that often occur misconceptions among students include: electrical material about electrical circuits [8], [9], kinematics [10], concepts of energy, momentum dan impulses [11], [12], greenhouse effect [13], dynamic fluid [14], heat, temperature, and internal energy [15], optical geometry and optical instruments [16], [17]. One of the topics of physics that have been confused by teacher candidates in understanding the topic is mechanical waves. Some researchers stated 34% of students were still indicated experienced misconceptions after receiving learning about mechanical waves, and 17.94% of students were still experiencing misconceptions after learning physics using interactive demonstrations [18],[19]. Students have the wrong intuition about the relationship between amplitude and frequency, and students have difficulty representing the graph of displacement to time. Fundamental concepts related to wave propagation phenomena, including mathematical representations of the general characteristics of moving waves, the movement of medium particles when traversed by waves, and the relationship $\lambda f = v$ are concepts that are difficult to understand by students [19],[20]. The concept of mechanical waves has a variety of properties that differ from intuition so it is difficult to understand. Obtained about 80% of high school students make guesses, and obtained about 50% of physics education students experience misconceptions [21], also more than 10% of respondents identified misconceptions with a high level of confidence [22].

Many researchers have proven many ways and strategies to reveal scientific concepts, conceptual changes and misconceptions on specific physics topics, namely by drawing [13], using concept mapping [23], and diagnostic tests [24], [25]. Diagnostic tests are tests used to know the weaknesses of students’ conceptual understanding so that the analysis results can be used as a basic step to provide follow-up in the exact treatment following the weaknesses experienced by students. A good diagnostic test can provide an accurate description of observing and recording the occurrence of error patterns. Diagnostic tests not only discover students’ misconceptions but gain a deeper understanding of how students think about answering questions even if their answers are incorrect. Multiple choice diagnostic tests have some types of tiers, it consists of two-tiers, three-tiers, and four-tiers diagnostic tests. The two and three tiers diagnostic tests can detect misconceptions, but all of these tiers have limitations. The two-tier test cannot determine correct answers caused by understanding concepts or guessing [26]. The weakness of the three-tier is that it does not know whether the respondent has a different confidence level between the first and second tiers, so the three-tier test estimates the low proportion of not understanding the concept and overestimates the score of respondents who understand the concept [26]. Research has been developed and resulted in a four-tier test with the confidence level in answers and reasons tiers,

separately. The four-tier test is one type of multi-tier multiple-choice diagnostic test. The assessment process using multiple-choice tests is usually easier to implement and assess [27].

Physics teacher candidate education that will produce physics teachers in an important topic related to human resources in education. Based on this explanation, the identification of students' misconceptions in physics education is one of the most important tasks in educational research. This research is intended as a reference for lecturers, teachers, and researchers to identify sub-topics of mechanical waves that have the biggest misconceptions so that they can give specific attention to eliminating misconceptions.

2. Research Methods

The main purpose of this research is to detect the misconceptions of physics education students about mechanical wave concepts. This research uses descriptive analysis research method that aims to describe systematically and factually about the facts of the variables being investigated.

2.1. Population and Sampling

The population in this research was physics education students in the Special Region of Yogyakarta. The research sample consisted of 35 physics teacher candidate' students. The sampling technique used was simple random sampling with the characteristics of students who had completed the first and second general physics courses and received learning about the concept of mechanical waves.

2.2. Data Collection Tools

The four-tier multiple-choice diagnostic instrument is a written test that is used to investigate the misconceptions of physics education students as physics teacher candidates.. the diagnostic instrument used in this research was the Four-Tier Waves Diagnostic Instruments (4WADI) developed by Caleon & Subramaniam [28]. 4WADI has been developed with the key stages of instrument development, namely : (1) Defining the Content Boundaries of the Study, (2) Exploratory Phase, (3) Content Validation and Piloting, (4) Construction, Administration and Validation of 4WADI. Some modifications were made in the second and fourth-tiers of 4WADI namely the confidence level made two choices of answers.

The diagnostic instrument consisted of 12 items about the mechanical wave concepts that were used to detect students' misconceptions with four tiers. The first tier of the diagnostic instrument contains multiple-choice questions with several answer choices. The second tier shows the confidence level of respondents to the answer (the first tier) with two answer choices. The third tier contains several choices of reasons for an answer (the first tier). The fourth tier is the confidence level of respondents with two choices of answers to the reasons chosen. Empty space is provided for students to write their reasons, if they cannot find an explanation that matches the answers (the first tier) among the choices in the third tier.

2.3. Data Analysis

Respondents' answers to each item in 4WADI are stated in four-tiers of decision level based on five categories of respondent distribution. Five categories of respondent distribution are (1) Scientific Conception, (2) Lack of Knowledge, (3) False Positive, (4) False Negative, and (5) Misconception. The physics education student answer decisions about understanding the wave concept are classified and analyzed using table 1 [2].

Table 1. Combination of decision level answers.

Answer (First-Tier)	Confidence Rating (Second-Tier)	Scientific Reason (Third-Tier)	Confidence Rating (Four- Tier)	Decision Category
Correct (C)	Confident (C)	Correct (C)	Confident (C)	Scientific Conception (SC)
Correct (C)	Confident (C)	Correct (C)	Unconfident (U)	Lack of Knowledge (LK)
Correct (C)	Unconfident (U)	Correct (C)	Confident (C)	Lack of Knowledge (LK)
Correct (C)	Unconfident (U)	Correct (C)	Unconfident (U)	Lack of Knowledge (LK)
Correct (C)	Confident (C)	Wrong (W)	Confident (C)	False Positive (FP)
Correct (C)	Confident (C)	Wrong (W)	Unconfident (U)	Lack of Knowledge (LK)
Correct (C)	Unconfident (U)	Wrong (W)	Confident (C)	Lack of Knowledge (LK)
Correct (C)	Unconfident (U)	Wrong (W)	Unconfident (U)	Lack of Knowledge (LK)
Wrong (W)	Confident (C)	Correct (C)	Confident (C)	False Negative (FN)
Wrong (W)	Confident (C)	Correct (C)	Unconfident (U)	Lack of Knowledge (LK)
Wrong (W)	Unconfident (U)	Correct (C)	Confident (C)	Lack of Knowledge (LK)
Wrong (W)	Unconfident (U)	Correct (C)	Unconfident (U)	Lack of Knowledge (LK)
Wrong (W)	Confident (C)	Wrong (W)	Confident (C)	Misconception (MSC)
Wrong (W)	Confident (C)	Wrong (W)	Unconfident (U)	Lack of Knowledge (LK)
Wrong (W)	Unconfident (U)	Wrong (W)	Confident (C)	Lack of Knowledge (LK)
Wrong (W)	Unconfident (U)	Wrong (W)	Unconfident (U)	Lack of Knowledge (LK)

3. Results and Discussion

Diagnostic tests have been successful in gradually monitoring student conceptualism and can provide information about efficient learning [28]. The data analysis results in Table 2 show the frequency and percentage of 35 physics education students who have been recapitulated according to the combination of answers in Table 1. This data shows the frequency of concept understanding based on problem indicators on each topic. Following this is the percentage of mechanical wave categories shown in Table 2.

Table 2. The recapitulation of the conceptual identification using The 4WADI.

No	Problem Indikator for Each Topics	Item	Frequencies and percentages of students' categories										Misconception of each topics	
			SC		LK		MSC		FP		FN			
			<i>f</i>	%	<i>f</i>	%	<i>f</i>	%	<i>f</i>	%	<i>f</i>	%	<i>f</i>	%
1	General characteristics of waves and wave motion represented in the graph	<i>Q1</i>	9	25,7	3	8,6	20	57,1	1	2,9	2	5,7	34	32,4
		<i>Q2</i>	18	51,4	9	25,7	5	14,3	3	8,6	-	-		
		<i>Q7</i>	2	5,7	14	40,0	9	25,7	6	17,1	4	11,4		
2	Determine the properties of longitudinal waves	<i>Q3</i>	12	34,3	11	31,4	6	17,1	3	8,6	3	8,6	9	12,9
		<i>Q4</i>	4	11,4	19	54,3	3	8,6	1	2,9	8	22,9		
3	Speed of wave in a medium with constant medium characteristics	<i>Q5</i>	3	8,6	16	45,7	10	28,6	-	-	6	17,1	31	29,5
		<i>Q6</i>	4	11,4	11	31,4	9	25,7	10	28,6	1	2,9		
		<i>Q8</i>	2	5,7	18	51,4	12	34,3	-	-	3	8,6		
4	Wave motion versus particle motion	<i>Q9</i>	11	21,4	12	34,3	9	25,7	1	2,9	2	5,7	18	25,7
		<i>Q10</i>	4	11,4	16	45,7	9	25,7	4	11,4	2	5,7		
5	Waves frequency, waves source & medium properties	<i>Q11</i>	5	14,3	13	37,1	14	40,0	2	5,7	1	2,9	21	30,0
		<i>Q12</i>	13	37,1	10	28,6	7	20,0	5	14,3	-	-		

SC: Scientific Conception; LK: Lack of Knowledge; MSC: Misconception; FP: False Positive; FN: False Negative

The data analysis results in table 2 show that 32.4% of students' answers were detected experiencing misconceptions about the general characteristic of mechanical waves and wave motion represented in the graph. 12.9% of students' misconceptions were detected in determining the properties of longitudinal waves. In addition, 29.5% of students' misconception occurred when determining the wave propagation speed in a medium with constant wave properties. Students' answers experienced misconceptions about wave motion to particle motion by 25.7% and students' misconceptions when determining wave frequency, wave source, and properties of a medium by 30.0%. In addition to misconceptions, the data analysis results have identified each student's conception abilities in the graph of decision answer categories. Following the percentage of students' conceptual abilities in terms of each problem indicator is shown in figure 1.

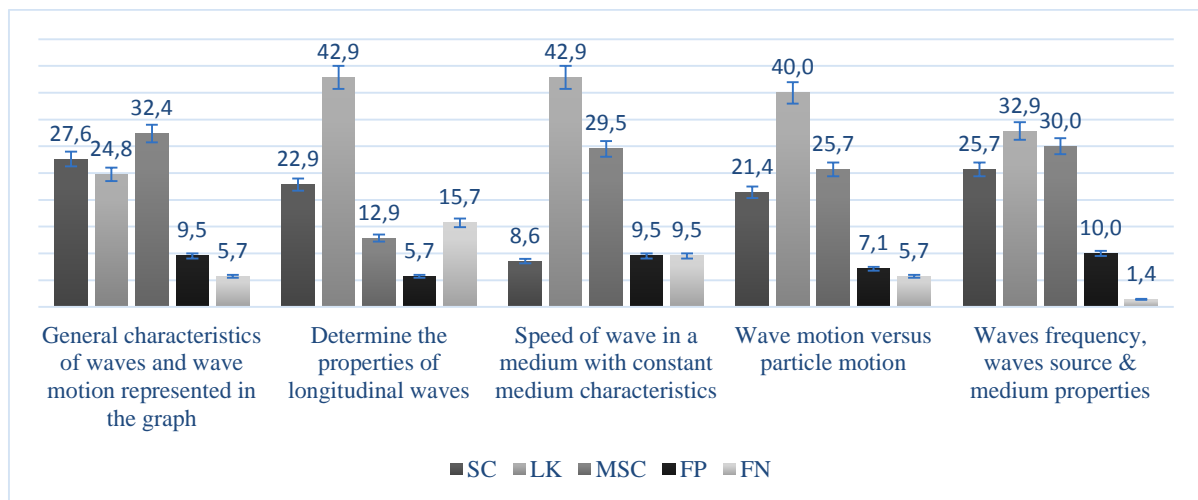


Figure 1. Percentage of students' conceptual categories for each problem indicator.

Figure 1 explains the graphic conceptual ability of physics education students on the topic of mechanical waves. Student misconceptions on the problem indicators of each topic, can be presented into several sub-topics on mechanical waves and shown in table 3.

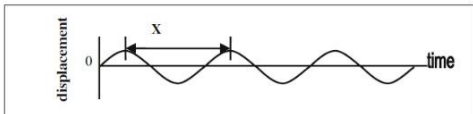
Table 3. Misconceptions of each sub-topic on mechanical waves.

No	Problem Indikator for Each Topics	Students' Answers including misconceptions
1	General characteristics of waves and wave motion represented in graph	<p>"The distance between the consecutive wave peaks in the graph of displacement with time is called the wavelength"</p> <p>"Sinusoidal graphs can only represent a particle in graph of displacement to time in a string when a wave passes through it"</p> <p>"No matter how the source of a wave moves, as long as the motion is periodic, the resulting motion of the particle in the medium will follow a sinusoidal path"</p>
2	Determine the properties of longitudinal waves	<p>"Error in amplitude identification from longitudinal wave graph"</p> <p>"The difficulty of distinguishing between compression and rarefaction, also determines the wavelength of the distance between compression and rarefaction"</p>
3	Speed of wave in a medium with constant medium characteristics	<p>"As the waves frequency increases, the speed of the wave also increases"</p> <p>"The energy and speed of the wave will not change, if the frequency is not change and amplitude increases"</p> <p>"Ropes must be jerked stronger and faster to produce pulse waves that propagate faster toward the ends of the ropes"</p>

No	Problem Indikator for Each Topics	Students' Answers including misconceptions
4	Wave motion versus particle motion	<p>"The wave and medium particles propagating through the medium move with the same speed"</p> <p>"Waves causes the movement of particles, this also makes the particles of medium follow the waves speed that propagate through the medium"</p> <p>"Waves causes the movement of particles, this also makes the particles of medium and the waves through the medium have the same speed"</p>
5	Waves frequency, waves source & medium properties	<p>"The frequency of waves will decrease if the waves propagate from a medium with a smaller density to a medium with a greater density"</p> <p>"A medium with greater mass has greater inertia. Fewer waves can propagate through it in a given time"</p>

The following is one of the items that has the biggest misconception seen from the way students answer questions about the sub-topic about the general characteristics of mechanical waves and wave motion represented in graph. The following item items are shown in figure 2.

Q1. The graph below shows the displacement of a particle in a medium against time as a wave propagates through the medium. What property of the wave is represented by the interval shown by X?



Answer : A. Frequency B. Period C. Wavelength

Confidence Rating : A. Unconfident B. Confident

Scientific Reason for My Answer:

- It is the distance between two successive crests of the wave
- It is the distance between any two points where maximum displacement of the particle occurs
- It is the time needed for the particle to complete one cycle of motion during the passage of the wave
- It is the number of complete waves that pass the particle in a given time
-

Confidence Rating : a. Unconfident b. Confident

Figure 2. The 4WADI example was developed by Caleon & Subramaniam [28] with modifications in second and fourth-tiers.

Figure 2 explains the concept of mechanical waves regarding general characteristics and the basis for students' conceptual understanding. The difficulty that appears when working on this problem item is when recognizing the characteristics of the waves that apply to the graph of the displacement with time (y-t) and the graph of the displacement with distance (y-x). Many students do not respond to each label listed on each axis of the graph and assume all wave charts have the same variable on each axis. Students see the graph as a representative wave propagation through the medium. This is the reason for the number of students who experience misconceptions of 57.1% and are categorized high.

Although the results of data analysis prove the lack of students' knowledge and misconceptions related to physics material is very large, the need for treatment and application of different learning methods to eliminate misconceptions and lack of conceptual knowledge. This statement is supported by Bilal & Erol [8] who explained that the application of the right method is modeling. Modeling methods can improve scientific ability, which is generally not done when teaching with conventional methods. Modeling can form hypotheses, experiment, collect and record data, represent phenomena that occur in physical equations appropriately, followed by evaluation and discussion stages so that they have the ability to solve problems and reconstruct true conceptual understanding. Another learning method developed to overcome the problem of misconception is the analogy method [29]. Also, another appropriate ways to remedy the lack of conceptual knowledge is by creating and representing physics

concepts, and utilizing technological advancements such as mobile physics-based virtual learning applications [9], [30]. This important ability must be possessed by teacher candidates or instructors.

4. Conclusion

This research may not have used a complete approach, but it is useful to display the conceptual profile of the physics teacher candidates with student misconceptions on each sub-topic of mechanical waves that are highly categorized and need specific attention to carry out remediation. This finding might be used as a reference for lecturers or teachers to consider sub-topics of mechanical waves that have a high potential for misconceptions. Therefore, lecturers and teachers can apply efficient and effective learning methods and strategies to eliminate students' misconceptions.

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