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ORIGINAL ARTICLE

Three-Tier Open-Reason Test: Analyzing Misconceptions and Obstacles Students through Individual-Centered Written Verbal Representations on Physics Concept

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ABSTRACT

This study investigates students' conceptions of the free-fall motion concept. The three-tier open-reason test was used as an instrument to diagnose students' conceptual understanding. A total of 20 high school students (10 males and 10 females) participated in this study. The analysis focused on individual-centered verbal written representations to uncover students' understanding, misconceptions (MCs), and the reasoning behind their answers. The results indicate that the most dominant MCs is the belief that gravity does not act in a vacuum. While some students demonstrated partial or sound understanding, many provided guessing or non-scientific answers. Rasch analysis was employed to measure individual student abilities and map item difficulty, enabling the identification of students who require targeted interventions. These findings highlight the importance of addressing specific MCs and applying tailored instructional approaches to enhance conceptual understanding in physics.

KEY WORDS: Conceptions, free fall motion, misconceptions, obstacles, physics concepts

INTRODUCTION

Misconceptions (MCs) often become a problem for students and even teachers regarding certain material. According to Larkin (2012); Saputra et al. (2019), MCs refers to a false or erroneous understanding of a concept or idea. This often occurs when a person has a wrong interpretation of certain information or ideas, which can be caused by various factors such as lack of knowledge, limited experience, or incorrect interpretation of the information received (Amiruddin et al., 2024; Erman, 2017; Samsudin et al., 2021; Smith III et al., 1994). MCs can occur in various fields, including physics, mathematics, science, language, and other fields. Detecting and addressing MCs is important to ensure a correct and accurate understanding of a concept. Continuous MCs possible become obstacles for students in understanding certain concepts. One example is the MCs related to the concept of free fall motion in physics.

Several previous studies have revealed MCs about the concept of free fall motion (e.g., Anggoro et al., 2017; Halim et al., 2021; Körhasan, 2021; Wancham et al., 2023). The previous studies only mapped in groups related to MCs categories with the number of frequencies. Previous studies have not examined students individually or explored their potential using the Rasch model approach. Based on this point, this research used three-tier open-reason test (TeTToT) and is combined with Rasch analysis so that it not only presents data in groups with categories but also presents them individually. On the other hand, it also presents the perspective of student answers through the open-reasons test given. Rasch analysis has become very popular in presenting statistics individually (e.g., Amiruddin et al., 2024; Arnold et al., 2018; Arthurs and Kowalski, 2022). That way, individual obstacles can also be seen to conduct more effective evaluations.

Obstacles in learning physics need to be known so that learning approaches can be adjusted and improved. By understanding the obstacles faced by learners, educators can identify more effective strategies to overcome MCs, increase conceptual understanding, and facilitate more effective learning. One thing that can be done to identify MCs and obstacles is through a diagnostic test. According to Kirbulut and Geban (2014), Kaltakci-Gurel et al. (2017), Caleon, and Subramaniam (2010), tests that are able to reveal MCs are tests in the form of tiers consisting of several levels or levels of difficulty, which aim to measure understanding of concepts in stages. This research uses the TeTToT to map MCs and investigate students' obstacles to the concept of free fall motion and to look at individual-centered verbal written representation in detail. Apart from that, it also uses Rasch analysis to map the abilities of student. Some questions that will be answered in this research are as follows:

- R_1: What are the student's conceptions of the concept of free fall motion?
- R_2: How does each student's ability relate to the difficulty level of the items?
- R_3: What are the reasons and obstacles that students reveal their through verbal written representations in understanding the concept of free-fall motion?

METHODS

Research Design

This research uses a qualitative descriptive method to analyze the MCs and obstacles experienced by students based on test results regarding the concept of free fall movement. These results are analyzed and mapped according to the selected rubric criteria and presented according to individual-centered verbal written representations based on MCs and obstacles through open-reasoning. According to Creswell and Poth (2016), the qualitative method of description is a method that is very useful in understanding in-depth phenomena, one example is in the field of education. In this context, researchers will present individual student data, which is confirmed by student perceptions in the open-reasoning test.

Participants

Participants in this research were 20 students (10 males) and (10 females) in class 12 of a high school from one school in Sidoarjo, East Java. East Java has a special nickname for males (Mas) and females (Mbak). Participants in this study ranged in age from 17 to 18 years. The researcher chose grade 12 students due to they had received free fall motion material, so the researcher had a goal to identify related to their mastery of the concept. The research locations are presented in Figure 1.

Collections Data

This research employed TeTToT instrument to examine students' conceptual understanding, reasoning, and confidence levels when answering physics questions. The concept assessed in this study was free-fall motion, which students had previously learned in Grade 10. The TeTToT instrument was designed based on the three-tier test (Peşman and Eryılmaz, 2010), with a modification in Tier-2 using open-responses to capture students' reasoning. The open-reasoning format in Tier-2 was intended to explore students' written perspectives underlying their answers in Tier-1. This approach enables a more in-depth representation written verbal of students' conceptions related to the assessed free-fall motion concept. Meanwhile, Tier-3 was maintained to measure students' confidence levels, thereby distinguishing the TeTToT instrument from a Two-Tier test. This data collection was carried out online using a Google form, which was then monitored by the teacher in the classroom. As an example, the question is presented in Figure 2.

Data Analysis

The data were analyzed using Microsoft Excel and Ministep Rasch software to generate individual-level information. Responses to Tier-1 were used as data to map students' abilities, in which correct answers were coded as 1 and incorrect answers were coded as 0. Subsequently, descriptive analysis was conducted based on the open-ended reasoning responses in Tier-2. Tier-2 focuses on identifying learning obstacles and incorrect conceptions related to the concept of free-fall motion, as reflected in the reasoning associated with Tier-1 responses. Meanwhile, Tier-3 continued to measure students' levels of confidence. To comprehensively determine students' conceptions of the assessed concepts, the results from all tiers were analyzed integratively refer to Coştu (2008); Samsudin et al. (2017); Peşman and Eryılmaz (2010), which is presented in Table 1.

RESULTS AND DISCUSSION

What is the Student's Conception of the Concept of Free Fall?

This report analyzes the conceptions of 20 students, divided evenly between female (P) and male (L) participants, based on their responses to two questions. The categories assessed are sound understanding (SU), partial understanding (PU), MCs, and no understanding (NU), shown in Table 2.

Question 1 in Table 2 shows that 35% of students demonstrated SU, 45% showed PU, 10% had MCs, and 10% had NU. Breaking this down by gender, 50% of female students had SU,

Figure 1: Research location

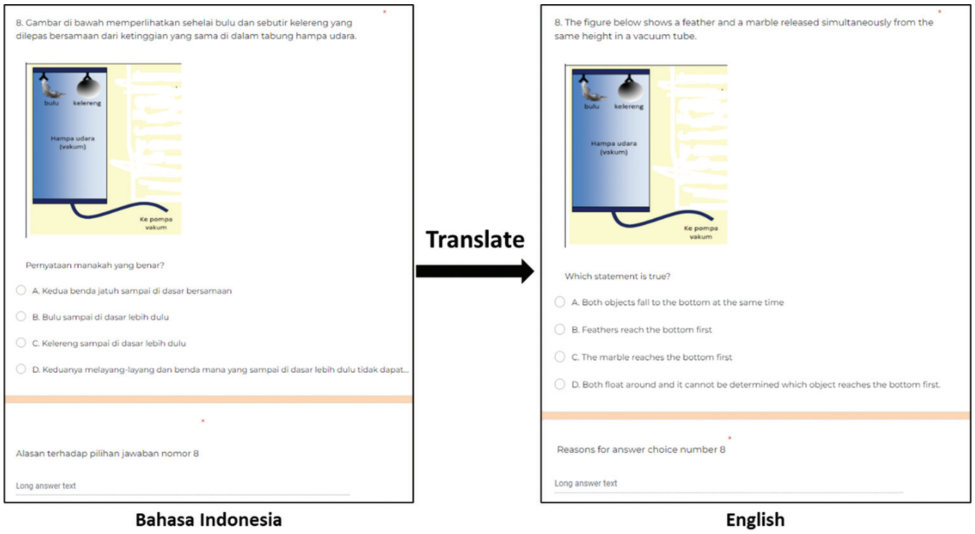

Figure 2: Example of a TeTToT (Adapted from Suryanti et al., 2013)

Table 1: Conception category

Tier-1	Tier-2	Tier-3	Category
Correct	Correct	Confident	Sound understanding
Correct	Correct	Not sure	Partial understanding
Correct	Wrong	Confident	
Correct	Wrong	Not sure	
Wrong	Correct	Confident	
Wrong	Wrong	Confident	Misconception
Wrong	Wrong	Not sure	No understanding

40% had PU, none had MCs, and 10% had NU. In contrast, 20% of male students had SU, 50% had PU, 20% had MCs, and 10% had NU. Question 2 shows that only 5% of students demonstrated SU, 55% showed PU, 35% had MCs, and 5% had NU. Among female students, none had SU, 50% had PU, 50% had MCs, and none had NU. Male students showed 10% SU, 60% PU, 20% MCs, and 10% NU.

The overall findings reveal that PU is the most common level of comprehension for both questions. However, SU significantly drops for Question 2 compared to Question 1. Female students tend to have a higher percentage of SU for Question 1, while male students show consistent PU across both questions. MCs are notably more prevalent in Question 2, indicating a need for targeted instructional strategies to address these misunderstandings. In addition, the consistent percentage of NU suggests that a subset of students requires extra support to improve their comprehension. Tailored educational approaches, considering gender differences, could further enhance overall student performance and understanding (Wang et al., 2014; Wang and Degol, 2017; Wehrwein et al., 2007).

How Does Each Student's Ability Relate to the Difficulty of the Items?

Rasch modeling is an effective method for measuring individual student abilities (e.g., Amiruddin et al., 2023; Engelhard Jr, 1992; Planinic et al., 2019). Using this model, a more detailed and accurate analysis can be carried out to ability each student's of the subject matter (Sumintono and Widhiarso, 2015). Rasch modeling allows us to calibrate problem difficulty and student ability on the same scale, so we can see clearly how each student interacts with each problem (e.g., Bond and Fox, 2013; Deonovic et al., 2020; Wright, 1977). In this section, it is only presented concerning the level of students' abilities in Figure 3.

Figure 3 represents the output of a Rasch analysis showing measures of individual student performance on a set of items. Key elements include entry number, total score, total count, Joint Maximum Likelihood Estimation measure, model standard error, mean square infit statistic, and outfit (MNSQ) and scor-z standardized, point-measure correlation, and percentage of exact matches (observed and expected). From the analysis results, students with the maximum measurement scores (e.g., 01PD, 06PD, 08PD, and 12LD) are identified as students with high abilities. These students had a high measure of ability, with a score of around 3.05, and a perfect score (100%) for the match between observed and expected. Their match statistics (infit and outfit MNSQ) are close to 1, indicating a good fit for the model (Susanto et al., 2018). In contrast, 29LD students had a minimum measure score (−2.95), indicating much lower ability. These students showed large deviations with lower performance, having an observed match of 30% compared to the expected match of 90%. Nonetheless, the fit statistics for 29LD are within an acceptable range, but highlight this student as an outlier.

The overall mean measure for all students was 1.22 with a standard deviation of 1.76, reflecting the variability of students' abilities. Fit statistics (average infit and outfit MNSQ) are close to 1, indicating that the model generally fits the data well. The overall observed and expected match percentage reached 90%, indicating a high degree of model fit. Furthermore, we know that gender influences a person's abilities. This is in line with

Table 2: Category conception of students

Questions	Category (code)	Students code	Percentage
1	Sound understanding	02PD,03PD,04PD,05PD,10PD,11LD,18LD	35
	Partial understanding	01PD,06PD,07PD,08PD,12LD,13LD,15LD,17LD,20LD	45
	Misconception	16LD,29LD	10
	No understanding	09PD,14LD	10
2	Sound understanding	18LD	5
	Partial understanding	01PD,04PD,06PD,08PD,09PD,11LD,12LD,13LD,15LD,16LD,17LD	55
	Misconception	02PD,03PD,05PD,07PD,10PD,29LD,20LD	35
	No understanding	14LD	5

ENTRY NUMBER	TOTAL SCORE	TOTAL COUNT	JMLE MEASURE	MODEL S.E.	INFIT MNSQ	INFIT ZSTD	OUTFIT MNSQ	OUTFIT ZSTD	PTMEASUR-AL CORR.	PTMEASUR-AL EXP.	EXACT MATCH OBS%	EXACT MATCH EXP%	Person
1	2	2	3.05	2.16	MAXIMUM MEASURE				.00	.00	100.0	100.0	01PD
6	2	2	3.05	2.16	MAXIMUM MEASURE				.00	.00	100.0	100.0	06PD
8	2	2	3.05	2.16	MAXIMUM MEASURE				.00	.00	100.0	100.0	08PD
12	2	2	3.05	2.16	MAXIMUM MEASURE				.00	.00	100.0	100.0	12LD
13	2	2	3.05	2.16	MAXIMUM MEASURE				.00	.00	100.0	100.0	13LD
14	2	2	3.05	2.16	MAXIMUM MEASURE				.00	.00	100.0	100.0	14LD
15	2	2	3.05	2.16	MAXIMUM MEASURE				.00	.00	100.0	100.0	15LD
16	2	2	3.05	2.16	MAXIMUM MEASURE				.00	.00	100.0	100.0	16LD
17	2	2	3.05	2.16	MAXIMUM MEASURE				.00	.00	100.0	100.0	17LD
2	1	2	.00	2.36	.11	-.63	.11	-.63	1.00	.80	100.0	90.0	02PD
3	1	2	.00	2.36	.11	-.63	.11	-.63	1.00	.80	100.0	90.0	03PD
4	1	2	.00	2.36	.11	-.63	.11	-.63	1.00	.80	100.0	90.0	04PD
5	1	2	.00	2.36	.11	-.63	.11	-.63	1.00	.80	100.0	90.0	05PD
7	1	2	.00	2.36	.11	-.63	.11	-.63	1.00	.80	100.0	90.0	07PD
9	1	2	.00	2.36	.11	-.63	.11	-.63	1.00	.80	100.0	90.0	09PD
10	1	2	.00	2.36	9.00	2.77	9.00	2.77	-1.00	.80	.0	90.0	10PD
11	1	2	.00	2.36	.11	-.63	.11	-.63	1.00	.80	100.0	90.0	11LD
18	1	2	.00	2.36	.11	-.63	.11	-.63	1.00	.80	100.0	90.0	18LD
20	1	2	.00	2.36	.11	-.63	.11	-.63	1.00	.80	100.0	90.0	20LD
19	0	2	-2.95	2.12	MINIMUM MEASURE				.00	.00	100.0	100.0	29LD
MEAN	1.4	2.0	1.22	2.25	1.00	-.29	1.00	-.29			90.0	90.0	
P.SD	.6	.0	1.76	.10	2.67	1.02	2.67	1.02			30.0	.0	

Figure 3: Person ability measures of students

Massa et al. (2005); Bian et al. (2017); Siswati and Corebima (2017), who state that gender influences someone's ability. Apart from that, it can also be influenced by social and cultural factors that shape perceptions and expectations of gender roles in education.

What are the Reasons and Obstacles that Students Reveal through their Verbal Written Representations in understanding the Concept of Free-Fall Motion?

Further analysis of the students continued with presenting the results of several of their open-reasoning answers at Tier-2. Even though they were right on the two questions given, many of the reasons given were wrong. Their short answers are presented with representatives of each question as follows:

Question 1.

> "*01PD: Because there is no force acting, the initial velocity is stationary*"
> "*07PD: No velocity yet*"
> "*09PD: I cheated*"
> "*12LD: I'm guessing*"
> "*15LD: Because velocity will increase earth's gravity*"
> "*29LD: Full guessing*"

Question 2.

> "*01PD: Because there isn't any gravity causing all things to fall together*"
> "*05PD: Because when there is no air objects will continue to float in the air*"
> "*07PD: Because the load on the marble is heavier*"
> "*08PD: Because in a vacuum the earth's gravity doesn't work well*"
> "*11LD: Because in a vacuum the law of gravity does not apply*"
> "*20LD: Because there is no gravity*"

Based on the answers given in Tier-2, it is known that there are still answers that are not by scientific concepts. The analysis of students' individual-centered verbal written representations reveals that while some students possess a correct understanding of initial velocity in free-fall motion, many exhibit significant MCs related to gravity, vacuum conditions, and mass dependency. Notably, a prevalent MCs is the belief that gravity does not exist or does not function in a vacuum. In addition, a considerable number of responses indicate the absence of conceptual understanding, as evidenced by guessing or non-serious answers. These findings highlight the importance of diagnostic assessments that incorporate open-ended reasoning to uncover the depth and nature of students' conceptual understanding.

This states that the obstacles that they experience can predict where some students have not mastered the concept as a whole. Mastery of scientific concepts is very important for all students to understand thoroughly, regardless of gender. Apart from that, the reasons why students serve the concepts still dominated the category of PU for each question. As for the scientific concepts in questions 1 and 2 are as follows:

Question 1 (Schwarz et al., 1998; Halliday et al., 2013):

> "*In free fall, the object will fall to the earth with a constant acceleration known as gravitational acceleration, which is usually denoted by the letters (g). On the surface of the earth, the value of gravitational acceleration is approx 9.8 m/s^2 and its direction is toward the center of the earth. Apart from that, this object is only influenced by gravitational force, without any other forces that influence it, such as air friction*."

Question 2 (Zatsiorsky, 2002; Halliday et al., 2013):

> "*At the start of the free-fall motion, no pushing force or initial force is acting on the object. This means that the object's initial velocity is zero because there is no force giving the object velocity. Even though the initial velocity is zero, the object will still fall downward because of the gravitational force pulling it downward. This gravitational force provides acceleration to objects and causes their velocity to increase over time. In addition, objects will experience changes in vertical velocity due to gravitational acceleration. This means that the object's velocity will increase every second by the value of the Earth's gravitational acceleration (g).*"

CONCLUSION

This study explored students' conceptions of the free-fall motion concept using the TeTToT combined with Rasch analysis. The findings indicate that while some students demonstrated a SU, the majority exhibited PU, and a significant portion held MCs. Analysis of students' individual-centered verbal written representations revealed that MCs were often related to gravity, vacuum conditions, and mass dependency, with many students also showing guessing or non-scientific reasoning. Rasch analysis further highlighted the differences in student abilities and the hierarchy of item difficulty, showing that some students have not yet fully mastered the concept. These results underscore the importance of diagnostic assessments and tailored instructional strategies to address individual learning obstacles.

This study has several limitations. First, the research sample is limited to high school students in one area, so generalization of the findings must be done with caution. Second, the use of TeTToT and Rasch analysis may not cover all aspects of students' understanding of the concept of free-fall motion. Third, other factors outside the school environment, such as students' cultural and educational backgrounds, may also influence their understanding.

This research has several important implications for physics teachers, particularly in utilizing TeTToT results to refine instructional strategies. First, the identification of students' MCs and learning obstacles through TeTToT can be used as diagnostic information to inform lesson planning and curriculum adjustment. Physics teachers can use these results to prioritize concepts that require conceptual reinforcement and to design targeted remedial activities. Second, TeTToT outcomes provide a basis for developing more adaptive and interactive teaching strategies, such as incorporating written verbal explanations, guided questioning, and reflective tasks that encourage students to articulate their reasoning. These strategies can help teachers respond more effectively to students' individual conceptual needs. Third, awareness of recurring MCs revealed by TeTToT enables teachers to explicitly address these MCs during instruction by contrasting students' initial ideas with scientifically accepted concepts. Then, physics teachers can enhance conceptual understanding and improve the overall quality of learning.

DATA AVAILABILITY STATEMENT

All data supporting the findings of this study are provided within the article. Anonymized participant data is available online, and the full dataset can be obtained by contacting the corresponding author.

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ETHICAL COMPLIANCE

All participants volunteered to take part in the study and had no objections to the publication of their answers. Their identities remain anonymous.

CONFLICTS OF INTEREST

The authors report that there is no conflict of interest in this paper.

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