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# Investigation into Popular Misconception about Free Fall-Insights through Diagnostic Test

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**Abstract - Free fall describes a straight line motion with constant acceleration when gravitational force is the only force acting on an object and is independent of the mass of the object. This is a perfect system to experiment with for studying the principles of kinematics.The primary objective of the study was to analyse student's misunderstandings about free fall in order to search for new instruction method to address them. The 15 items in diagnostic test on free fall were selected from 20 items following expert's advice and on the basis of level of difficulty and the indices of defined differences. Item Difficulty Index, Discrimination Index and Reliability coefficient are calculated for each test item. Student's difficulties in free fall are identified using this analysis.**

**Key Words: Free Fall, Diagnostic test, Misconceptions, Item Difficulty Index, Discrimination Index and Reliability coefficient**

## I. Introduction

It has been observed that free fall misconceptions are very common among the students [8]. If the graphical representations of the displacement, velocity and acceleration and their changes with time are not understood correctly, students cannot use them for deductive reasoning of related cases scenarios like tossing the ball, projectile motion etc. [10]. Though students understand acceleration vs. time graph correctly in free fall motion, the graph of displacement and velocity as a function of time revealed strong misconceptions both on the physical phenomenon and its inherent mathematical consistency [9]. Students get ideas from the day to day experiences and generalize them and create their own "theories". Traditional lecture method applied by most of the teachers does not consider the way students understand the concepts in physics - they tend to believe whatever the teacher says. Problem solving capabilities are consideredas the measure of conceptual understanding of the student. The most common misconceptions are about magnitude of velocity of an object at the various stages of a free fall and its dependence on the height of release and the objects' final speed and its independence from mass or weight of the object. Most of the students believe that heavier the object faster it falls [2]. This study aims to explore if the students who are taught free fall motion by traditional method are

able to interpret kinematical graphs and solve related problems. Misconceptions are assumed to be real by students and used consistently [4]. The misconception is not caused by a lack of knowledge, but the incomplete understanding in the wrong way. It is necessary to identify misconception by providing diagnostic tests. Diagnostic tests are useful for learning difficulties experienced by students [3]. Diagnostic tests have become the most effective assessment tools for identifying misconceptions of students [6].Without understanding the misconception in the students it will be difficult for teachers to identify students with difficulty learning to make the right policy to teach them[1].

## II. Methodology

Content surveys of 20 items were conducted on the topic of free fall to design the diagnostic test. This test was designed based on common difficulties of students as discussed with senior teachers and personal interviews.Diagnostic test was administered to the 231 undergraduate students from two different colleges.Item Difficulty Index, Discrimination Index and Reliability coefficient are calculated for each test item and difficulties in free fall are identified using this analysis [8].The 15 items in diagnostic test on free fall were selected from 20 items following expert's advice and on the basis of level of difficulty and the indices of defined differences. The test was validated by senior most teachers who are teaching mechanics.The reliability coefficient of the test has been determined according to Kuder-Richardson (KR-21) method and has been identified as 0.703.

Misconceptions were identified after discussion with the students and subject experts, on the basis of answers given to the questions in pilot test. Wrong answers were chosen on the basis of prevailing misconceptions on a particular item. The wording and the possible answers in the list were modified on the basis of student's feedback. Questions in this diagnostic tool are created on following concepts

- The object's initial velocity is considered zero m/s if it is dropped (not thrown) from a height.
- When an object is thrown in vertical direction, then speed starts decreasing as it rises upward. The velocity gradually becomes zero he instant body reaches the uppermost point.
- When an object is thrown in vertically upward direction, then its velocity at any position is equal in magnitude and opposite in direction during upward and downward journey.
- An object in free fall motion experiences an acceleration of -9.8 $m/s^2$ throughout the motion.
- Motion in freefall is independent of mass of the object. The mean velocity between two positions is the velocity at mid time when acceleration is constant.

Diagnostic test on free fall was in accordance with these research questions. The items of the test are based on interpretation and application of kinematics equations, interpretation of graphical representation and interpretation of verbal representation. Also to check the consistency of conceptual understanding, there is a link between the questions.

Student's responses on different items of the test are given in Figure1: This figure represents the consolidated outcome of the study.

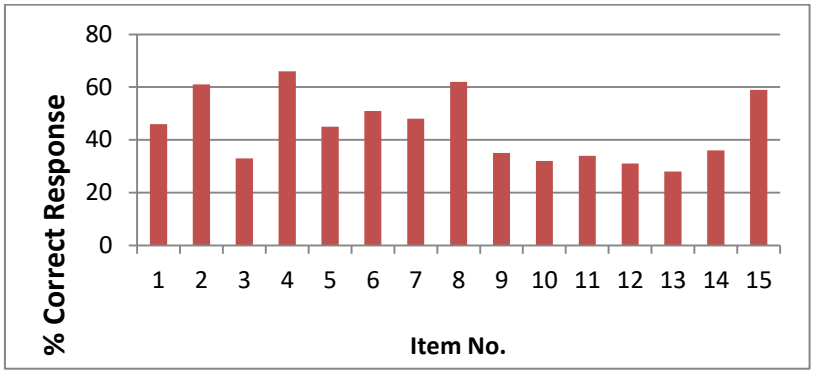


**Figure 1: Results of diagnostic test on free fall**

**Discrimination and Difficulty index of free fall test**

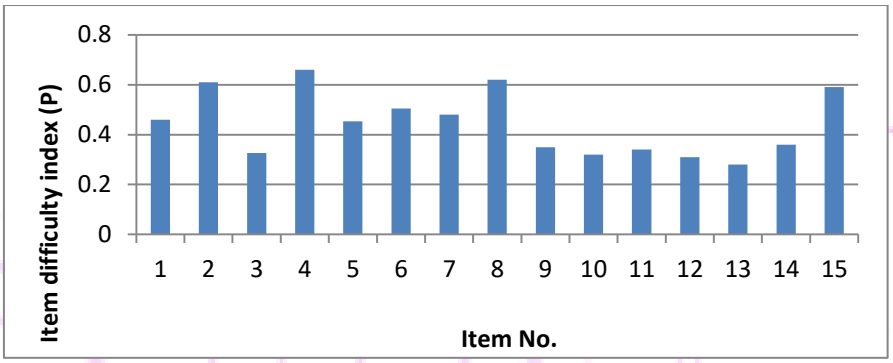


**Figure 2: Item difficulty index (P) for each question for free fall test**

After analysis of students responses on items in diagnostic test, item difficulty index and item discrimination index were determined for the test. To obtain difficulty index and discrimination index only correct responses were taken. These indices are given in the table 1. From item difficulty and discrimination indices average difficulty and average discrimination indices were calculated.Reliability index was used to test the consistency of the test.

**Table 1**

**Difficulty and Discrimination Index on free fall test**

| Item No. | % Correct Response | Index | |
|---|---|---|---|
| | | Difficulty (P) | Discrimination (D) |
| 1 | 46 | 0.46 | 0.64 |
| 2 | 61 | 0.61 | 0.52 |
| 3 | 33 | 0.33 | 0.44 |
| 4 | 66 | 0.66 | 0.68 |
| 5 | 45 | 0.45 | 0.6 |
| 6 | 51 | 0.51 | 0.52 |
| 7 | 48 | 0.48 | 0.72 |
| 8 | 62 | 0.62 | 0.64 |
| 9 | 35 | 0.35 | 0.48 |
| 10 | 32 | 0.32 | 0.64 |
| 11 | 34 | 0.34 | 0.44 |
| 12 | 31 | 0.31 | 0.4 |
| 13 | 28 | 0.28 | 0.32 |
| 14 | 36 | 0.36 | 0.44 |
| 15 | 59 | 0.59 | 0.64 |
| Average | 44.46 | 0.44 | 0.54 |

**The variation of discrimination index with respect to difficulty index is given in Figure 3.**

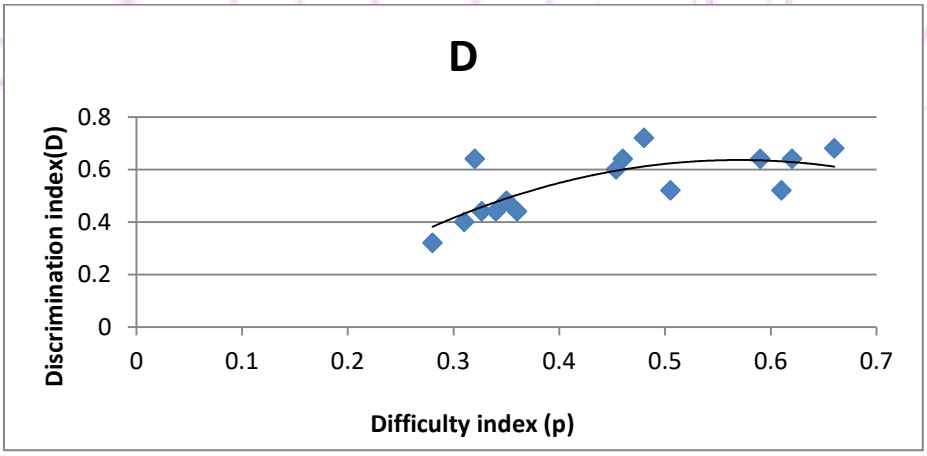


**Figure 3: The relationship between P and D values of the test on free fall**

The figure 3suggests that majority of test items have acceptable level of difficulty and excellent values of discrimination index [8]. The test items with moderate level of difficulty index are very good discriminators and the items which demonstrated poor discrimination has very low or very high difficulty level [7].

**Point biserial coefficient ($r_{bps}$)**

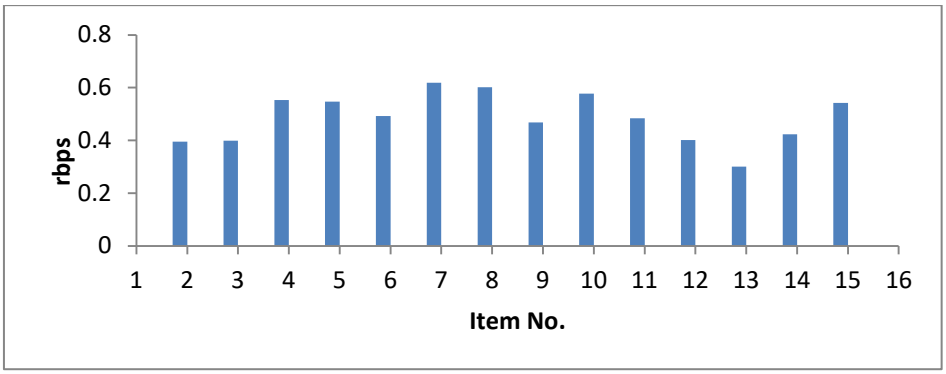


**Figure 4: Point biserial coefficientfor each question for free fall test**

**Free fall diagnostic test items and responses**

For each item student's difficulty and misconception they hold regarding the related concept is explained.

The Questionnaire on free fall in Appendix I

Item 1 is included in the questionnaire to check the students' ability to solve the kinematics equation for a freely falling object. The wrong options could be chosen by the students due to the misconception which was found from discussion with students they intuitively thought that, if the initial velocity is doubled, then the maximum height to which the ball will reach will also double. This implies that students have tried to solve the question intuitively without applying kinematics equation. The 2 included in the questionnaire to check the ability of the student to apply correct kinematics equation and to see if they have concept of direction of acceleration. Students have chosen wrong options because his concept of direction is not clear. This shows that most of the students recognize this as a simple mathematical problem (as opposed to a conceptual problem requiring interpretation) and are able to apply the correct equation of motion. The item 3 is included in the questionnaire to check the concept that when an object reverses direction of motion it instantaneously comes to rest to do this. Some students gave the response that the velocityat highest point in motion is zero, the ball comes to rest at that point. Many students believe that as the object is continuously jumping, it never comes to rest. Some students gave the response that the ball comes to rest when it reaches the position 0 only. Item 4 is included in the questionnaire to check the concept of direction and magnitude of gravitational acceleration when the body is undergoing freefall motion. Many students have a misconception that at the topmost point the acceleration is zero because velocity is zero. Many students have misconception that acceleration due to gravity is 9.8 $m/s^2$; they are unaware of the fact that it is always negative whether the body is moving vertically upward or downward under freefall motion. Some students answered that acceleration due to gravity changes from+9.8 $m/s^2$ to -9.8 $m/s^2$, since at the highest point the direction of motion of the body changes from vertically upward to downward the value of acceleration due to gravity changes. Item 5 included in the questionnaire to check the understanding of the velocity time graph and the concept of direction and change in magnitude of velocity of a freely falling object. Some students have chosen the option in which velocity of the object becomes zero after it touches the ground, as it stops at the end of motion. Students choosing this option did not understand the problem but considered only the end state (which is outside the problem). Some students have interpreted the direction of velocity in the graph also wrongly, they have considered on the magnitude of velocity. Some students have chosen the graph of constant negative velocity. Item 6 is included in the questionnaire to check the concept that freefall motion is independent of mass of the object. Most of the students have answered that heavier object fall faster than lighter, they misunderstand and expect heavier object to fall faster based on their experience, not realizing the condition

for air friction is dropped. Some students have chosen the option; heavier object will take half the time because its mass is double the mass of lighter object. This option student will choose because they thought intuitively that the same force is applied so lighter will move faster and since the mass is half so it will take half the time.In item 7, a situation was given where a ball is released from the roof of a tower to the ground and was asked, at which position the velocity of the ball is highest. Some of the students have answered that the velocity is highest in the middle of the path, since they believe that the body is at rest at the highest point and on the surface of earth so it should be highest in the middle. Most of the students answered that the velocity is highest at the ground since velocity increases as he body falls towards the surface of earth. Some students have chosen the option that velocity is highest at roof.

In item 8 students had to find the time the ball will take to reach maximum height, if its velocity is 2v, as compared to the time it will take when the velocity is v. Students intuitively think that if velocity is doubled the time taken to reach the highest point will become half.

In this test item four different graphs of position versus time, of a ball which is thrown upward in vertical direction with initial speed of 19.8 m/s were given and students had to choose the correct one. This question was included to check student's ability to solve kinematics problem graphically. Most of the students could calculate maximum height reached but the shape of graph these students could not judge properly.
In item 10, a situation was given where a ball is thrown inverticaldirection along a path from position 0, it reaches highest height at position 5 and it falls to strike the ground at position 0. The students had to compare the velocity at position 2, between position 0 and position 5 while rising and while falling. Some students who do not have the concept of direction have answered that velocity will be equal. Some students have chosen the option that velocity while rising will be higher than the velocity while falling. Probably because of the misconception thatthe velocity will decrease progressively as the body goes up. Therefore earlier we measure it the higher it will be. Most of the students chose the option that velocity while falling will be greater. These students intuitively think that falling body will move faster because of gravity. Item11 is included in the questionnaire to check the concept of direction and magnitude of initial velocity graphically when it is dropped from a moving body at height H. When the object is dropped from a balloon moving upward, it has constant positive upward velocity at t = 0 due to the balloon and the downward velocity due to downward negative gravitational acceleration which increases as it moves downward. Velocity will become zero at a particular time but the acceleration will be -9.8 $m/s^2$ because of which velocity will increase in downward direction. Final velocity depends upon the height from which it started falling. Most of the students chose the option in which initial velocity is zero they did not understand that the initial velocity will be positive, and when it falls down velocity will increase in downward (negative) direction. Some of the students chose the option in which initial velocity is positive but it increases in the positive direction for them probably the concept of direction of velocity when the object is moving downward is missing. Item 12 is a situation given in which an object is thrown downward from some height in the absence of air friction, it bounces elastically and caught at a height below the starting point. Some students have chosen the option which shows that they probably understood the point of discontinuity in the magnitude of velocity but did not have the concept of direction. Some students tried to recreate the shape of the path probably they were mixing up the velocity with the shape of the path in the graph. Most of the students partly interpreted the initial motion correctly but has not understood the result of elastic collision. This shows that students find it very difficult to represent verbal description of motion graphically.

Item 13 is included in the questionnaire to check the concept that average velocity between two positions in constant acceleration motion is the velocity at mid time. In this item tabular data of displacement versus time at different positions is given and students had to identify correct velocity versus time graph. This item is based on the concept that average velocity between two positions in constant acceleration motion is the velocity at mid time.Most of the students have chosen the option with zero velocity at t = 0 s and increases negative direction.

In item 14 four different graphs of velocity vs. time were given and students had to identify the correct graph for motion of an object thrown vertically upward and is caught below its starting point, if upward direction is taken as positive. Some students have chosen the graph similar to the path of motion in shape, probably they are mixing up the velocity with the shape of the path in the graph, and they are trying to recreate the shape of the path. Most of the students have chosen the option in which the direction of velocity during the downward motion is increasing in positive direction. Choice of this option suggests that students do not have concept of direction, he considered only the magnitude. Some of the students are confused between velocity and displacement they chose the graph with parabolic shape.

Item 15 the gravitational acceleration of the ball thrown vertically upward, reaches its highest height and then falls down in vacuum is asked. This item is included in the questionnaire to check the meaning of freefall. Some of the students chose the option that acceleration is in the direction of motion. Some students chose the option that freely falling bodies can only move downward and gravitational acceleration acts only on falling bodies. Some of the students answered that when the body is moving upward its velocity changes because of the force applied at the time of throw, not because of gravitational acceleration. Some students answered that gravitational acceleration does not act in vacuum.

## III. Result and Discussion

(1) Students have difficulty in understanding that freefall motion is independent of mass of the object. They feel that time to fall for a heavier mass will be less than that for a lighter object because intuitively they think that the heavier body will move faster under force of gravity based on their experience.

(2) Students mix up the velocity with the shape of the path in the graph, they try to recreate the shape of the path during free fall motion.

(3) Students have difficulty understanding the meaning of constant negative acceleration. When the body is thrown vertically upward with some initial positive velocity as it goes up its velocity decreases and finally at the highest point it becomes zero, then it falls down with increasing negative velocity. The velocity at a point lower than the starting point will be more because the velocity is increasing as it is moving down.

(4) Students do not understand that average velocity between two positions in constant acceleration motion is the velocity at mid time.

(5) Students have difficulty understanding that when an object is thrown in vertically upward, then its velocity at any point in path is equal in magnitude and opposite in sign during upward and downward motion.

(6) Students have difficulty understanding the concept that when an object reverses direction of motion it instantaneously comes to rest to do this. When an object is thrown upwards in a perfect vertical direction, it reaches maximum height at which it reverses direction of motion and momentarily comes to rest to do this. When the ball bounces on the ground it again reverses direction and to this it momentarily comes to rest.

(7) Students do not understand that an object in free fall motion experiences an acceleration of -9.8 $m/s^2$ throughout the motion.

(8) Students do not understand that the initial velocity of the object is considered zero if the body is dropped from a height and it is not zero when it is thrown up.

(9) Students have misconception that freely falling objects can only move downward and gravity only acts when the body is falling.

(10) Students have misconception that there is no gravity in vacuum.

## IV. Conclusion

The result of data analysis shows that there are two basic concepts that are crucial for the understanding of free fall motion: the concept of constant downward negative acceleration and the concept of equal but opposite velocity at same height during upward and downward motion. The results indicates that students have ability to memorize the graphs of the physical phenomenon but have serious difficulty applying concepts while solving problem based on these concepts.Thus the test instrument can be used as a diagnostic tool in a formative way and is useful for providing feedback for the students and for the teacher on Free Fall concepts. The results of data analysis show that qualitative understanding of Free Fall concepts and the skill of interpretation of kinematics graphs is missing in the students when taught by traditional method.

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