

STUDENTS' MISCONCEPTIONS ABOUT FORCE AND MOTION: A CASE STUDY

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Abstract

Force and motion are foundational concepts in school physics, but students may develop alternative conceptions that differ from scientifically accepted Newtonian explanations. The present classroom-based case study examined the pre-test and post-test performance of 20 Class XI students of PM Shri Government Senior Secondary School Dhanger, Patiala. The study used a one-group pre-test/post-test design. The available record contained individual scores for both assessments. The mean pre-test score was 6.85 (SD = 1.09), while the mean post-test score was 13.90 (SD = 0.85), giving a mean improvement of 7.05 points. All 20 students improved on the post-test. A paired-samples t-test showed a statistically significant difference between the two assessments, $t(19) = 20.97$, $p < .001$. The findings indicate substantial improvement in assessed performance following the learning period. However, the supplied record contains total scores rather than item-level responses, so specific misconception categories cannot be quantified from these data alone. The study therefore interprets the results as evidence of improved assessed understanding and recommends item-wise diagnostic assessment for future identification of specific misconceptions.

Keywords

Force; motion; misconceptions; conceptual understanding; physics education; Class XI; pre-test; post-test; case study

1. INTRODUCTION

Physics learning is not limited to memorizing equations and definitions. Meaningful learning requires students to construct scientifically coherent explanations of physical phenomena. Force and motion are particularly important because they form the foundation of mechanics and are connected to everyday experiences such as walking, braking, pushing objects and the motion of vehicles.

Students enter physics classrooms with ideas developed through everyday observation. Some of these ideas are useful in ordinary life but can conflict with Newtonian physics. Research in physics education has documented recurring difficulties involving force, velocity, acceleration, inertia, friction and Newton's laws. The Force Concept Inventory was specifically developed to assess conceptual understanding of Newtonian force concepts and to reveal common alternative conceptions.

The present study was undertaken by Baljit Singh, Lecturer Physics, at PM Shri Government Senior Secondary School Dhanger, Patiala, with Class XI students. It focuses on students' performance before and after classroom learning related to force and motion.

An important distinction is made in this paper between improvement in test scores and identification of specific misconceptions. A total score can show that performance has changed, but it cannot by itself reveal why a student selected an answer or which alternative conception was responsible. Specific misconceptions require item-level responses, distractor analysis, or interviews. This distinction is important for accurate reporting of classroom research.

2. REVIEW OF RELATED LITERATURE

Halloun and Hestenes investigated students' common-sense beliefs about motion and its causes and developed a taxonomy of ideas that conflict with Newtonian theory. Their work demonstrated that students' prior conceptions can strongly influence physics learning.

Hestenes, Wells and Swackhamer subsequently developed the Force Concept Inventory, a conceptual instrument designed to assess students' beliefs about force and motion. The inventory includes concepts associated with kinematics and Newton's first, second and third laws.

These studies support the use of diagnostic assessment rather than relying exclusively on conventional numerical examinations. In particular, item-level responses can reveal whether students distinguish velocity from acceleration, understand the meaning of net force, recognize inertial motion, and correctly interpret interaction pairs.

The present case study is smaller in scale and is based on the actual pre-test and post-test score record available for the selected Class XI students. It therefore complements, rather than reproduces, large-scale diagnostic research.

3. OBJECTIVES OF THE STUDY

1. To examine the pre-test performance of Class XI students on the assessed force-and-motion content.
2. To examine the post-test performance of the same students.
3. To compare students' pre-test and post-test scores.
4. To determine whether the observed change in scores is statistically significant.
5. To discuss implications of the findings for classroom teaching of force and motion.

4. RESEARCH QUESTIONS

6. What was the level of students' performance in the pre-test?
7. What was the level of students' performance in the post-test?
8. Did students' scores improve between the two assessments?
9. Is the observed pre-test/post-test difference statistically significant?
10. What are the implications of the findings for physics classroom practice?

5. METHODOLOGY

5.1 Research Design

A quantitative, classroom-based one-group pre-test/post-test case-study design was adopted. The same 20 Class XI students were represented in both assessment records. This design is suitable for examining change within the selected classroom group, but it does not by itself establish that a particular instructional method caused the change because there was no separate control group.

5.2 Participants and Setting

The study was conducted at PM Shri Government Senior Secondary School Dhanger, Patiala, Punjab. The participants were 20 students of Class XI. The analysis uses student identification numbers rather than publishing students' names in the results tables.

5.3 Data Source

The supplied record contains 20 pre-test scores and 20 corresponding post-test scores. The pre-test scores range from 5 to 9, and the post-test scores range from 12 to 15. The uploaded record does not state the maximum possible score and does not contain the individual test questions or item-wise responses. Accordingly, this paper reports raw scores and paired change rather than percentage scores or normalized gain.

5.4 Data Analysis

Descriptive statistics included mean, standard deviation, median, minimum and maximum scores. The paired difference was calculated for each student. A paired-samples t-test was used to compare the pre-test and post-test means because the two measurements came from the same students. The significance level was set at .05.

6. RESULTS

6.1 Descriptive Statistics

Statistic	Pre-test	Post-test	Mean change	n	Interpretation
Mean	6.85	13.90	7.05	20	Increase
SD	1.09	0.85	1.50	20	—
Minimum	5	12	—	20	—
Maximum	9	15	—	20	—
Median	7	14	—	20	—

The mean pre-test score was 6.85, whereas the mean post-test score was 13.90. The mean paired improvement was 7.05 points. All 20 students showed an increase in score. The paired-samples t-test gave $t(19) = 20.97$, $p < .001$, indicating a statistically significant difference between the two assessment occasions.

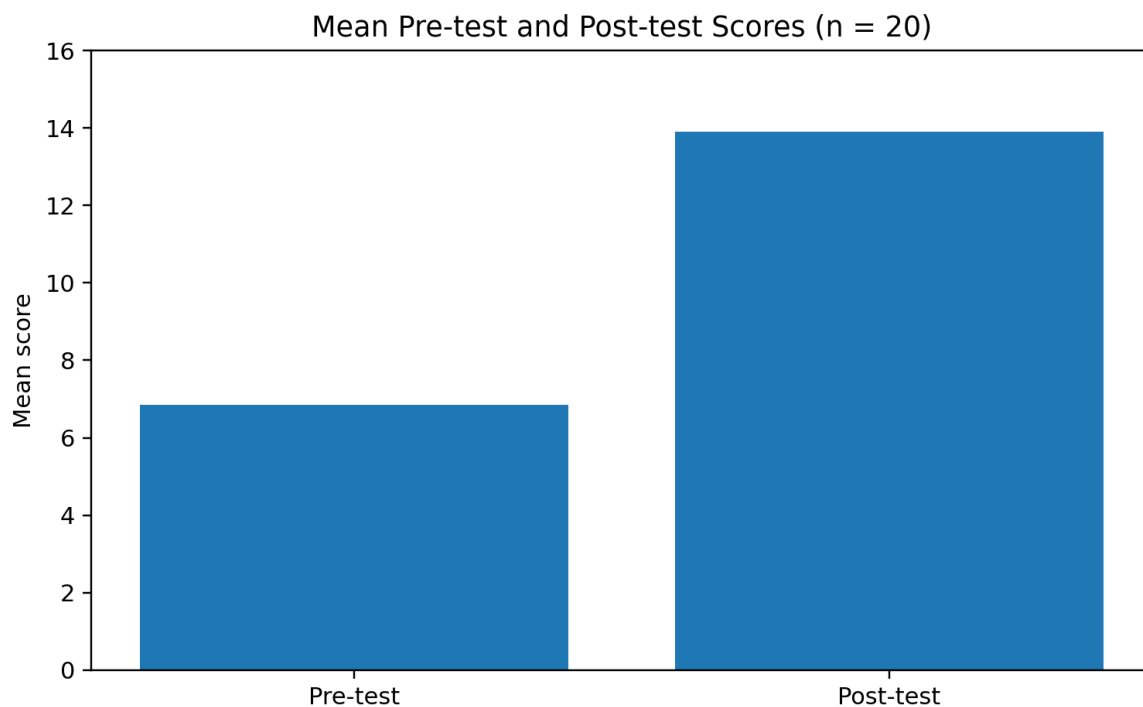


Figure 1. Mean pre-test and post-test scores of the 20 students.

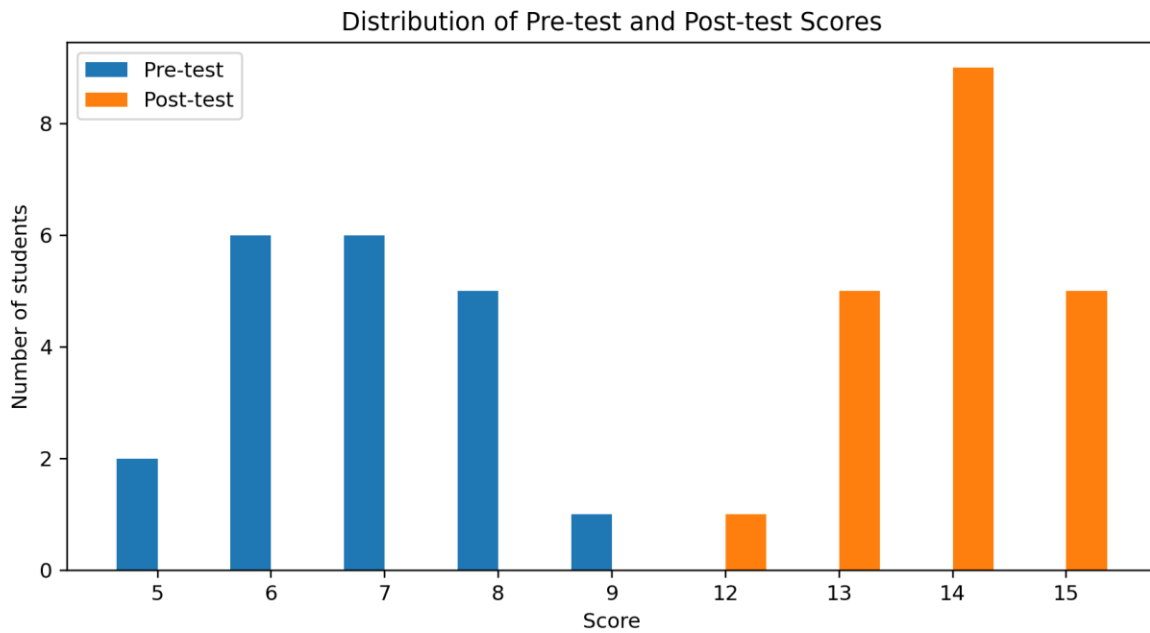


Figure 2. Distribution of pre-test and post-test scores.

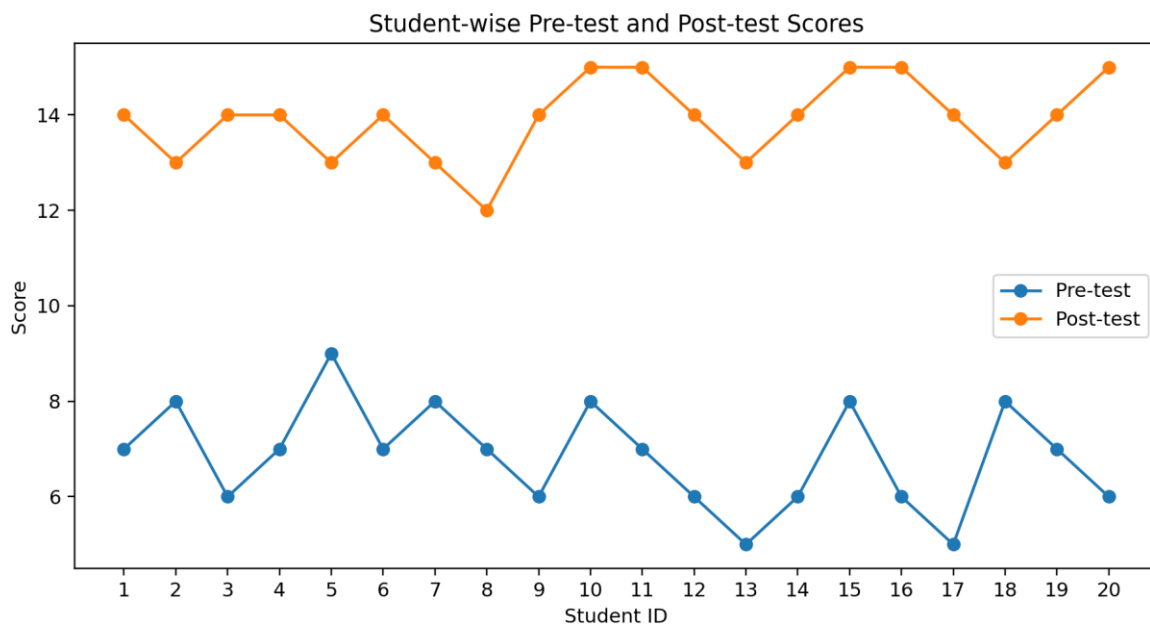


Figure 3. Student-wise comparison of pre-test and post-test scores.

6.2 Student-wise Change

Student ID	Pre-test	Post-test	Change
1	7	14	7
2	8	13	5
3	6	14	8
4	7	14	7

5	9	13	4
6	7	14	7
7	8	13	5
8	7	12	5
9	6	14	8
10	8	15	7
11	7	15	8
12	6	14	8
13	5	13	8
14	6	14	8
15	8	15	7
16	6	15	9
17	5	14	9
18	8	13	5
19	7	14	7
20	6	15	9

7. DISCUSSION

The results demonstrate a clear improvement in assessed performance from the pre-test to the post-test. The average score increased by 7.05 points, and every student recorded a higher post-test score. The statistical test confirms that the observed difference is unlikely to be explained by random paired variation alone.

The improvement is educationally encouraging, but it should be interpreted within the limits of the design. A one-group pre-test/post-test study cannot isolate the effect of a specific teaching strategy because other factors may contribute to score changes. In addition, the available data do not show which questions were answered incorrectly before instruction or which conceptual errors remained after instruction.

The study title refers to misconceptions because force-and-motion learning is known to involve persistent alternative conceptions. However, a rigorous claim about a specific misconception requires diagnostic response data. For example, the belief that an object needs a continuing force to maintain motion, or confusion between acceleration and velocity, should be identified from students' actual responses rather than inferred from a low total score. Research on the Force Concept Inventory and earlier mechanics diagnostic work supports this item-level approach. ☐ cite ☐ turn0search0 ☐ turn0search6 ☐

Thus, the present results support the conclusion that students' assessed performance improved, while the next stage of the research should examine item-level misconception patterns. This distinction strengthens the validity and academic integrity of the case study.

8. EDUCATIONAL IMPLICATIONS

- Use conceptual questions in addition to numerical problems.
- Ask students to explain their reasoning for both correct and incorrect answers.
- Use demonstrations and experiments involving balanced and unbalanced forces.
- Use free-body diagrams to help students distinguish individual forces from net force.
- Use pre-test results to plan remedial and enrichment teaching.
- Use post-test item analysis to identify concepts that require further instruction.
- Encourage students to test their predictions against observations rather than relying only on everyday intuition.

9. LIMITATIONS

- The sample contains only 20 students from one school, limiting generalization.
- There was no control group, so causal claims about a particular instructional intervention cannot be made.
- The available record contains total scores rather than item-level responses.
- The maximum possible score is not specified in the source record, so percentages and normalized gain were not calculated.
- The exact instructional activities conducted between the two assessments were not documented in the supplied score sheet.

10. CONCLUSION

This case study examined pre-test and post-test performance of 20 Class XI students at PM Shri Government Senior Secondary School Dhanger, Patiala. The mean score increased from 6.85 to 13.90, representing an average improvement of 7.05 points. All 20 students improved, and the paired-samples t-test showed a statistically significant difference, $t(19) = 20.97$, $p < .001$.

The findings indicate substantial improvement in the assessed performance of the selected students. At the same time, the study highlights the need to distinguish improved test scores from direct identification of specific misconceptions. Future versions of the study should preserve item-wise responses and students' explanations so that misconceptions about force, motion, Newton's laws, friction, velocity and acceleration can be identified and quantified accurately.

11. SUGGESTIONS FOR FURTHER RESEARCH

11. Develop or use an expert-reviewed conceptual diagnostic test specifically for Class XI force-and-motion concepts.
12. Record item-wise answers and reasons for selecting each answer.
13. Include a comparison/control group where feasible.
14. Conduct short student interviews to investigate the reasoning behind selected misconceptions.
15. Compare different teaching approaches such as demonstrations, laboratory activities, simulations and peer instruction.
16. Conduct delayed post-tests to determine whether conceptual gains are retained.

12. REFERENCES

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APPENDIX A: DATA NOTE

The numerical analysis in this paper was calculated from the pre-test and post-test score record supplied by the researcher. Student names were not reproduced in the manuscript tables; student IDs 1–20 are used for the paired comparison. The source record is the basis for all numerical results in this paper.

APPENDIX B: PRE-TEST INSTRUMENT

Pre-Test: Misconceptions about Force and Motion (Case Study Diagnostic Assessment)

Topic Areas Covered: Newton's Laws, Constant Velocity, Acceleration, Circular Motion, Friction, Gravity, Impulse, Apparent Weight, and Centripetal Force.

Q1. Topic: Force and Constant Velocity

A puck glides across a perfectly frictionless horizontal air hockey table. Once it has been struck by a mallet, what happens to the horizontal force acting on the puck as it moves across the table?

- A. The horizontal force gradually decreases until the puck stops.
- B. The horizontal force remains constant and equal to the initial impact force.
- C. There is no horizontal force acting on the puck after it leaves the mallet.
- D. The horizontal force increases as the velocity increases.

Q2. Topic: Newton's First Law

A heavy wooden crate is pushed across a rough horizontal floor at a steady, constant speed of 1.0 m/s. How does the magnitude of the pushing force compare to the magnitude of the kinetic friction force?

- A. The pushing force is equal in magnitude to the kinetic friction force.
- B. The pushing force is greater than the kinetic friction force.
- C. The pushing force is less than the kinetic friction force.
- D. The pushing force equals the maximum static friction, which is greater than kinetic friction.

Q3. Topic: Velocity vs. Acceleration

A student tosses a heavy metal ball straight up into the air. At the exact highest point of its vertical trajectory, what are the ball's velocity and acceleration?

- A. Velocity is zero, and acceleration is zero.
- B. Velocity is maximum, and acceleration is downward at 9.8 m/s^2 .
- C. Velocity is upward at 9.8 m/s , and acceleration is zero.
- D. Velocity is zero, and acceleration is downward at approximately 9.8 m/s^2 .

Q4. Topic: Acceleration in Uniform Circular Motion

A communications satellite orbits Earth in a perfectly circular path at a completely constant speed of 7.8 km/s. Is there an acceleration acting on the satellite?

- A. No, because the speed is uniform and does not change over time.
- B. Yes, there is an acceleration directed toward the center of Earth.
- C. Yes, there is an acceleration directed forward in the direction of the velocity vector.
- D. No, because gravity is balanced completely by centrifugal force in orbit.

Q5. Topic: Newton's Third Law

A massive semi-truck collides head-on with a small, lightweight compact car. During the brief duration of the impact, how do the magnitudes of the force exerted by the truck on the car and the force exerted by the car on the truck compare?

- A. The truck exerts a much larger force on the car than the car exerts on the truck.
- B. The car exerts a larger force on the truck because it crumples more easily.
- C. The forces are exactly equal in magnitude.
- D. Neither vehicle exerts a force on the other; the damage is caused purely by kinetic energy transfer.

Q6. Topic: Newton's Third Law Application

A horse pulls a cart forward along a flat road. According to Newton's Third Law, the cart pulls back on the horse with an equal and opposite force. If the forces are equal and opposite, how is the horse able to accelerate the cart forward?

- A. The external friction force between the horse's hooves and the ground is greater than the backward force of the cart on the horse.
- B. The horse pulls harder on the cart than the cart pulls on the horse during the moment of acceleration.
- C. The cart moves because the horse's momentum overcomes the cart's inertia before the reaction force can register.
- D. Newton's Third Law only applies to stationary objects, not accelerating systems.

Q7. Topic: Gravity and Mass

Inside a high-vacuum chamber, a solid lead cannonball and a hollow plastic sphere of the exact same outer diameter are released simultaneously from a height of 5 meters. Which object hits the floor first?

- A. The solid lead cannonball hits first because gravity pulls much harder on massive objects.
- B. The hollow plastic sphere hits first because it encounters less internal resistance.
- C. The lead cannonball hits first because air pockets inside the plastic sphere cause a buoyant delay.
- D. They hit the floor at exactly the same time.

Q8. Topic: Impulse and Momentum

To safely stop a moving car, a driver can slam on the brakes for a short time or gently apply the brakes over a longer time interval. Which option minimizes the braking force required, and why?

- A. Short time interval, because a rapid stop requires less overall work done by the brakes.
- B. Longer time interval, because impulse states that force is inversely proportional to time for a given change in momentum.
- C. Short time interval, because static friction is higher than kinetic friction during abrupt stops.
- D. Longer time interval, because it increases the mass of the car relative to the road.

Q9. Topic: Apparent Weight and Normal Force

An elevator is moving upward and is actively slowing down as it approaches the top floor. What is the relationship between the passenger's apparent weight (the normal force exerted by the floor) and their true gravitational weight (mg)?

- A. Normal force is greater than mg because the elevator is moving upward.
- B. Normal force is equal to mg because constant or changing speed doesn't alter weight inside an elevator.
- C. Normal force is less than mg because the acceleration is directed downward.
- D. Normal force is zero because the passenger experiences temporary weightlessness.

Q10. Topic: Friction Misconceptions

A heavy wooden block is given a sharp push and slides up a rough inclined plane, eventually coming to a stop and sliding back down. What is the direction of the kinetic friction force acting on the block while it is moving up the incline?

- A. The kinetic friction force points down the incline, opposing the motion.

- B. The kinetic friction force points up the incline, helping to push the block higher.
- C. The kinetic friction force is zero because the initial push is the dominant force.
- D. The kinetic friction force points horizontally because the normal force acts perpendicular.

Q11. Topic: Distinguishing Velocity and Acceleration

Car A is traveling at a massive speed of 120 km/h on a straight highway with cruise control engaged. Car B is traveling at 40 km/h on a side street, but the driver is pressing the gas pedal hard to merge quickly. Which car experiences a net external force in the direction of motion?

- A. Car A, because higher speed requires a much larger continuous net forward force to maintain.
- B. Both cars experience an identical net forward force because both are in motion.
- C. Neither car experiences a net force since they are both driving on ordinary roads.
- D. Car B, because it is actively speeding up (accelerating), whereas Car A has zero acceleration.

Q12. Topic: Action-Reaction Pairs vs. Balanced Forces

A heavy physics textbook rests completely stationary on a flat horizontal wooden table. If Earth's gravitational pull on the book is considered the 'action' force, what is the exact corresponding 'reaction' force according to Newton's Third Law?

- A. The upward normal force exerted by the table on the textbook.
- B. The upward gravitational pull exerted by the textbook on Earth.
- C. The downward force exerted by the textbook on the table.
- D. There is no reaction force because the book is stationary and not moving.

Q13. Topic: Centripetal Force

A small rubber ball is swung in a horizontal circle at the end of a light string. If the string suddenly snaps at the exact position where the ball is directly to the north of your hand, in what path does the ball initially move?

- A. It continues moving in a curved, circular path that spirals outward.
- B. It flies directly straight outward away from your hand (radially north).
- C. It moves along a straight line pointing directly toward the east (tangent to the circle).
- D. It immediately drops straight down to the ground due to the loss of upward tension.

Q14. Topic: Net Force in Curvilinear Motion

A simple pendulum swings back and forth in a vertical arc. At the very bottom of its swing (the lowest point of the arc), what is the direction of the net force acting on the pendulum bob?

- A. The net force points straight upward toward the pivot point.
- B. The net force is completely zero because the bob is momentarily balanced.
- C. The net force points horizontally in the direction of the upcoming swing.
- D. The net force points straight downward, matching the force of gravity.

Q15. Topic: Newton's Third Law Case Study

An athlete pushes firmly against a massive, immovable concrete retaining wall with a horizontal force of 350 N. The wall does not budge or shift. What magnitude of force does the concrete wall exert back on the athlete?

- A. 0 N, because the wall is completely rigid and immovable.
- B. A value less than 350 N, proportional to how much the wall resists deformation.
- C. A value greater than 350 N, because the wall has massive structural inertia.
- D. 350 N.

APPENDIX C: POST-TEST INSTRUMENT & ANSWER KEY

Post-Test: Misconceptions about Force and Motion (Conceptual Evaluation & Answer Key)

A 15-question conceptual evaluation to assess understanding after the instructional unit, complete with correct answers and explanatory physics rationales.

1. Inertial Motion in Deep Space

A space probe is drifting in deep space, completely out of reach of any significant gravitational pull from stars or planets. If its engine shuts off completely, what will happen to its motion?

- A) It will immediately come to an absolute stop.
- B) It will gradually slow down and eventually stop as its initial force dissipates.
- C) It will continue moving forward in a straight line at a constant speed.**
- D) It will curve back toward the last planet it passed due to gravitational memory.

Explanation: *Correct Answer: C. According to Newton's First Law, an object in motion stays in motion with a constant velocity unless acted upon by an external net force. No continuous force is needed to maintain motion in a frictionless vacuum.*

2. Constant Speed Sled Motion

You pull a heavy sled across a flat snow-covered field at a constant, unvarying velocity. If the friction force between the sled and the snow is exactly 50 Newtons, what is the magnitude of the pulling force you exert?

- A) Exactly 50 Newtons.**
- B) Slightly more than 50 Newtons to keep it from stopping.
- C) Significantly more than 50 Newtons to overcome its static inertia.
- D) Less than 50 Newtons because it is already moving.

Explanation: *Correct Answer: A. Constant velocity means the acceleration is zero. By Newton's Second Law, the net force must be zero, meaning the forward pulling force perfectly balances the backward friction force.*

3. Peak of Vertical Trajectory

A toy rocket is launched straight up into the air. At the absolute peak of its flight path, right before it begins to fall back down, what are its velocity and acceleration values?

- A) Velocity is zero; acceleration is zero.
- B) Velocity is zero; acceleration is 9.8 m/s^2 downward.**
- C) Velocity is maximum; acceleration is 9.8 m/s^2 upward.
- D) Velocity is changing upward; acceleration is zero.

Explanation: *Correct Answer: B. At the peak, the rocket stops moving for an instant ($v = 0$), but gravity never stops pulling on it, maintaining a continuous downward acceleration of approximately 9.8 m/s^2 .*

4. Uniform Circular Motion

A race car drives around a perfectly circular track at a steady, unchanging speed of 150 km/h. Which statement accurately describes the forces and acceleration acting on the car?

- A) The car has zero acceleration because its speed is constant.
- B) The car accelerates forward because its engine is working hard.
- C) The car accelerates toward the center of the track due to a net centripetal force.**
- D) The net force is zero because centrifugal force balances out the car's steering input.

Explanation: *Correct Answer: C. Velocity is a vector. Even if the speed is constant, the continuous change in the direction of motion constitutes an inward centripetal acceleration, which requires a net inward force.*

5. Vehicle-Insect Collision Interaction

A massive mosquito crashes directly into the windshield of a fast-moving highway truck. How does the magnitude of the force exerted by the truck on the mosquito compare to the force exerted by the mosquito on the truck?

- A) The truck exerts a vastly larger force on the mosquito.
- B) The mosquito exerts a larger force because it decelerates faster.
- C) The two forces are exactly equal in magnitude.**
- D) The mosquito experiences a force, but the truck experiences zero force.

Explanation: Correct Answer: C. Newton's Third Law states that forces always exist in equal and opposite pairs. The asymmetry in visible destruction is caused by the vastly different masses and structural strengths, not a difference in force.

6. Propulsion Mechanisms

A swimmer pushes off a concrete pool wall to accelerate forward through the water. Which force directly causes the swimmer to accelerate forward?

- A) The forward force the swimmer exerts onto the wall.
- B) The backward force the wall exerts onto the swimmer.**
- C) The internal muscular force of the swimmer's legs.
- D) The upward buoyant force of the water balancing gravity.

Explanation: Correct Answer: B. To accelerate an object, an external force must act on it. The swimmer pushes backward on the wall (action), and the wall reacts by pushing the swimmer forward (reaction).

7. Vacuum Acceleration of Free Fall

A feather and a heavy steel bolt are dropped at the exact same moment inside a specialized chamber from which all air has been completely evacuated. Which object reaches the bottom first?

- A) The steel bolt, because gravity pulls harder on objects with more mass.
- B) The feather, because its lower inertia allows it to react faster.
- C) They hit the bottom at the exact same time.**
- D) The steel bolt hits first because the feather retains an internal buoyant charge.

Explanation: Correct Answer: C. In a true vacuum, there is no air resistance. While gravity pulls with more force on heavier objects, they possess proportionally more inertia to overcome. All objects accelerate downward at the exact same rate (g).

8. Impulse and Impact Mitigation

An airbag is designed to deploy during a car crash to protect passengers. Using the concepts of impulse and momentum, how does the airbag safely minimize the impact force?

- A) It decreases the overall change in momentum experienced by the passenger.
- B) It shortens the time interval of the stop, bringing the passenger to rest instantly.
- C) It extends the time interval over which the passenger stops, reducing the required force.**
- D) It increases the mass of the steering column to absorb kinetic energy.

Explanation: Correct Answer: C. The equation $F \cdot \Delta t = \Delta p$ demonstrates that for a fixed change in momentum (Δp), increasing the duration of the impact (Δt) dramatically scales down the average force (F) applied to the passenger.

9. Apparent Weight in Decelerating Elevator

A passenger stands on a scale inside an elevator that is moving downward but is rapidly slowing down as it reaches the basement floor. How will the scale reading compare to the person's normal weight (mg)?

- A) The scale reading will be greater than their normal weight.**
- B) The scale reading will be less than their normal weight.
- C) The scale reading will be exactly equal to their normal weight.
- D) The scale reading will drop to zero because they are moving down.

Explanation: *Correct Answer: A. Moving downward while slowing down means the acceleration vector points upward. A net upward acceleration means the upward normal force from the scale must be greater than the downward force of gravity.*

10. Direction of Kinetic Friction

A heavy stone block is thrown along a flat, rough asphalt parking lot. It slides forward, gradually slows down, and comes to a complete halt. What is the direction of the kinetic friction force acting on the block while it slides?

A) In the direction of motion, helping the block slide further.

B) Opposite to the direction of motion, resisting the slide.

C) Pointing straight downward, adding to the block's weight.

D) Pointing straight upward, lifting the block slightly.

Explanation: *Correct Answer: B. Kinetic friction always acts parallel to the contact surfaces and points in the direction exactly opposite to the relative sliding velocity of the object.*

11. Net Force vs. Constant Speed

Car X cruises at a constant 100 km/h on a straight highway. Car Y starts from a complete stop at a red light and accelerates up to 30 km/h. Which vehicle experiences a non-zero net external force?

A) Car X, because maintaining a high speed requires a massive net forward force.

B) Car Y, because it is actively accelerating, which requires a net external force.

C) Both cars, because any vehicle in motion experiences a net external force.

D) Neither car, because ordinary passenger cars balance their own forces internally.

Explanation: *Correct Answer: B. Net force is directly proportional to acceleration ($F = ma$), not velocity. Car X has constant velocity ($a = 0$, so $F_{net} = 0$), while Car Y is accelerating ($a > 0$, so $F_{net} > 0$).*

12. Action-Reaction Pairs

A coffee mug rests completely still on top of a flat computer desk. If the downward gravitational force of the Earth pulling on the mug is the 'action' force, what is the true 'reaction' force?

A) The upward normal force exerted by the desk surface on the mug.

B) The downward force the mug exerts onto the desk surface.

C) The upward gravitational force exerted by the mug on the Earth.

D) There is no reaction force because the system is static.

Explanation: *Correct Answer: C. Action-reaction pairs must involve the exact same two interacting bodies. If Earth pulls down on the mug, the matching reaction is the mug pulling up on the Earth with equal magnitude.*

13. Tangential Velocity on Breakage

A ball tied to a string is swung in a uniform horizontal circle. If the string suddenly snaps when the ball is positioned directly east of the center, in what initial direction does the ball travel?

A) Directly east, flying straight outward away from the center.

B) Directly north or south, along the tangent line of its circular path.

C) It continues moving in a spiral path that gradually widens.

D) It drops straight down instantly, losing all horizontal velocity.

Explanation: *Correct Answer: B. When the centripetal force vanishes due to the string snapping, the ball's inertia carries it forward in a straight line along its instantaneous tangential velocity vector.*

14. Pendulum Bob Net Force

A heavy pendulum bob swings back and forth. At the absolute lowest point of its arc, what is the direction of the net force acting on the bob?

A) The net force is zero because it is momentarily level.

B) The net force points straight downward toward the ground.

C) The net force points straight upward toward the pendulum's pivot point.

D) The net force points horizontally in the direction the bob is traveling.

Explanation: *Correct Answer: C. At the lowest point, its speed is at a maximum (zero tangential acceleration), but it is following a curved path. This requires a centripetal acceleration pointing inward toward the center of the arc (upward).*

15. Static Action-Reaction

A strong child attempts to push a heavy brick retaining wall with a force of 100 Newtons, but the wall does not move at all. What is the magnitude of the force that the wall exerts back on the child's hands?

A) 0 Newtons, because the wall is static and unyielding.

B) Exactly 100 Newtons.

C) Less than 100 Newtons, depending on the static friction of the child's shoes.

D) More than 100 Newtons, because the wall possesses immense structural mass.

Explanation: *Correct Answer: B. According to Newton's Third Law, the force exerted by the child on the wall is always perfectly matched by an equal and opposite force exerted by the wall on the child, regardless of whether movement occurs.*

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