Developing Problem Solving and Critical Thinking Skills in Physics and Engineering Physics Courses

Parameswar Hari
Department of Physics and Engineering Physics, The University of Tulsa,
800 S. Tucker Dr., Tulsa, OK 74104

Abstract

Physics instruction at the university level is conducted through lectures, demonstrations, discussions, and problem solving recitation sessions. Students are tested and evaluated for their mastery of physical concepts through carefully designed problems in almost all physics courses. Unfortunately, several studies [1-3] show that traditional methods of problem solving may not be the best approach for developing problem solving skills and critical thinking in introductory physics courses. In this paper we discuss a new approach to teaching problem solving and critical thinking skills to physics and engineering physics students. We propose a new method in which physics students are asked to evaluate different solutions to a given problem and decide why a particular solution is the correct one compared to various other approaches leading to the exactly same final answer. This technique could facilitate critical thinking in students taking introductory physics courses.

Introduction

Physics is traditionally considered a difficult subject to master because of the high degree of problem solving skills demanded in learning the subject. Besides requiring a high level of mathematical skills, applying physical principles to text book problems is quite challenging to a vast majority of engineering and science majors. The main tool in measuring students' mastery of physics is through standard text book problems that require a numerical answer. Understanding of physics in a course is primarily evaluated based on the ability of student to obtain a correct answer to a given problem. Most often, for grading classes with large enrollments, instructors are forced to use multiple choice exams for evaluation. The key underlying assumption in assigning numerical physics problems is that a student who mastered physical principles should be able to solve a problem leading to a final correct answer.

One important question regarding this methodology is this: are we testing problem solving and critical thinking skills by assigning standard text book problems in quizzes and exams? A related issue is whether student learning is actually tested by evaluating solutions to numerical problems from text books. Is there another way to test the depth of understanding the principles involved in solving a physics problem?

The multiple solution approach: An example

In many introductory physics courses taught by the author, students often ask for the answer to even problems, which are not available in the text book. For a beginning physics student, obtaining the correct answer to a given problem is a sure way of testing their understanding of physical principles. Underlying this practice is the assumption that by obtaining the correct answer the student is likely to follow the correct application of the physical principles involved. This assumption can be challenged by providing multiple approaches to the same problem leading to the same final answer. If there is only one correct approach leading to the exact same answer among the multiple solutions presented, it requires significant thinking and evaluation on the part of the student to distinguish between various solutions. An example of this method is presented below based on a problem taken from a standard introductory college level physics text [4].

An example problem:

An 8 gram bullet is fired into a 250 g block that is initially at rest on a frictionless table. The block is located at the edge of the table. The table is 1 meter high above the ground. After the bullet gets lodged into the block, the block and bullet lands 2m from the bottom of the table. What is the initial speed of the bullet? Ans: 143 m/s.

In order to illustrate the problem solving technique developed in this paper we provide three solutions leading to the same answers.

Solution 1

First task in solving this problem is to find the horizontal speed V_x of the block and bullet immediately after the collision. Just after the collision, the block and the bullet become a projectile. Based on the physics of projectile motion we can analyze the problem to find the time taken by the block and bullet as:

Initial vertical y component of the block and bullet is zero. Thus from the kinematics equation

$$y = v_{y0} + \frac{1}{2} g t^2 \qquad (1)$$

where the symbols are defined as follows: y is the vertical height, v_{y0} is the initial velocity along the y direction, g the acceleration due gravity and t , the time for the motion.

we obtain, $$-1.0 = 0 - \frac{1}{2} * 9.8 * t^2 \qquad (2)$$

Eqn. 2 can be solved to obtain the time of flight as t = 0.452 s. Thus the initial horizontal speed of the block and bullet (Vx) just after collision is given by

$$V_x = x/t \qquad (3)$$

Substituting for x, the horizontal distance, = 2 m and t = 0.452 sec in Eqn. 3, we obtain V_x = 4.43 m/s. Applying conservation of linear momentum for the bullet –block system, we obtain

$$m_b v_b = (m_b + M_B) V_x \qquad (4)$$

where m_b and M_B are the mass of the bucket and the block respectively. V_b , the initial velocity of the bullet, is the quantity we are seeking. By substituting the mass of the bullet, the block, and the horizontal velocity of the block and the bullet in Eqn. 4, we obtain v_b = 143 m/s.

Solution 2

We start by applying the conservation of mechanical energy to the bullet block system,

$$(M_B + m_b)g\,H + \tfrac{1}{2}\,(M_B + m_b)\,Vx^2 = \tfrac{1}{2}\,(M_B + m_b)\,V_f^2 \quad (5)$$

where H is the initial height (1 m), M_B , mb are the mass of the block and bullet respectively, and V_x, V_f , are the initial speed and final speed of the bullet and block. The final speeds can be broken into x and y components and the magnitude is given by

$$V_f^2 = V_x^2 + V_y^2 \qquad (6)$$

Substituting Eqn 6 into Eqn 5 and solving for V_y, we obtain

$$V_y = \sqrt{2gH} \qquad (7)$$

Substituting values of H and g in Eqn. 7 , we will obtain the y component of the velocity Vy = 4.43 m/s. If we use the kinematics equations to solve for V_x at the beginning of free fall as in solution 1, we obtain the numerical result that $V_x = V_y$ = 4.43 m/s.

Using conservation of momentum, and setting $V_x = V_y$ = 4.43 m/s, we obtain from Eqn. 4, the final speed of the bullet as in solution 1 (v_b) equal to 143 m/s.

Solution 3

In this approach we will again use the conservation of mechanical energy for the mass bullet system and write kinetic and potential energy and set them equal to each other as below.

$$(M_B + m_b)\,gH = \tfrac{1}{2}\,(M_B + m_b)\,V_B^2 \qquad (8)$$

where the symbols M_B, m_b, and H were defined previously in solution 1 and 2. V_B is the speed of the bullet and the block after collision. From Eqn. 8, we also obtain the same value for the final velocity of the block and the bullet (V_B) equal to 4.43 m/s as in solution 1 and 2. Now, by applying conservation of linear momentum as in Eqn. 4, we obtain the initial speed of the bullet (v_b) as 143 m/s.

Critical evaluation of solutions

In this new problem solving approach, instead of presenting the correct answer with the correct approach, students are asked to critically evaluate each of the above solutions. Traditionally students associate wrong answers with wrong methods. In this case, all the three approaches yield exactly the same final answer. Instruction using this technique can ask students to defend each approach or explain why a particular solution is right or wrong. If it is wrong, how do you fix the solution? The main goal of this approach is to stimulate critical thinking. The above example is very valuable because it involves conservation of energy and momentum as well as the physics of projectile motion. Students who clear understood these principles will be able to pick the right solution and provide the correct reasoning for choosing a particular solution. In the example shown here, only a knowledgeable student will recognize that mechanical energy is not conserved in inelastic collisions and the approaches presented in solution 2 and 3 are wrong, even though the wrong physics produced the right answer. The key point here is that linear momentum is conserved in both elastic and inelastic collision, but mechanical energy is conserved only in elastic collisions.

An example of how this method can be used in an exam

In the problem below, each step to a final solution is given. In the space below each step indicate whether the step is true or false **and** justify your answer in each case. If you think a particular step is wrong, correct the solution and provide a justification for your correction. No points will be given for selecting only True or False.

Problem: An 8 gram bullet is fired into a 250 g block that is initially at rest on a frictionless table. The block is located at the edge of the table. The table is 1 meter high above the ground. After the bullet gets lodged into the block, the block and bullet lands 2m from the bottom of the table. What is the initial speed of the bullet? Ans: 143 m/s.

Step 1: $y = v_{y0} + ½\, g\, t$

where the symbols are defined as follows: y is the vertical height, v_{y0} is the initial velocity along the y direction, g the acceleration due gravity and t , the time for the motion.

True or False: Justify your answer.

Step 2: solving for time, $-1.0 = 0 - ½ * 9.8 * t^2$

From this Eqn., t = 0.452 s

True or False: Justify your answer.

Step 3: The initial horizontal speed of the block and bullet (Vx) just after collision is given by

$$V_x = x/t$$

True or False: Justify your answer.

Step 4: Applying conservation of linear momentum for the bullet –block system, we obtain

$$m_b v_b = (m_b + M_B)V_x$$

Note: m_b, M_B are respectively the mass of the bullet and the block. v_b is the initial speed of the bullet.

True or False: Justify your answer.

Step 5: By substituting the mass of the bullet, the block, and the horizontal velocity of the block and the bullet in Eqn. 4, we obtain the initial speed of the bullet, v_b = 143 m/s.

True or False: Justify your answer.

Summary

A problem solving approach is presented where students are asked to evaluate multiple solutions to a given physics problem, with all approaches leading to the same final answer. This approach is different from the traditional problem solving, where students are given one solution leading to a correct final answer. We believe that this approach could facilitate critical thinking and develop problem solving skills based on clear understanding of physical principles.

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Biographical Information

Dr. Hari is an assistant professor of physics and engineering physics at the University of Tulsa. Dr. Hari earned a Ph.D. from the University of Utah . After Ph.D., Dr. Hari received post-doctoral training at The NHMFL (National High Magnetic Field Laboratory), Texas A& M University and Vanderbilt University. Dr. Hari has published over 35 peer-reviewed articles and is represented in the 2006-07 edition of who's who among America's teachers.