Critical Thinking Integrated with Instructional Scaffolding Approach in Physics Classroom

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Abstract

The Case Study presents critical thinking with instructional scaffolding as a novel pedagogical approach in teaching a physics course. The approach is described in detail with the help of examples in introductory physics.

Keywords

Instructional scaffolding, physics learning, critical thinking, pedagogy

Introduction

Many students who scrape through Physics and Mathematics in their 12th Board Examination and still join Engineering stream find it very difficult to cope up with the physics syllabus in the first semester of their engineering education. We have come to realize that they attempt to learn the subject by rote without actually understanding the subject. The issue becomes more difficult for the students who do not come from English medium background. While there may be numerous ways to tackle this problem, we chose to improve critical thinking skills of students from scratch to an acceptable level. The first step towards this was to help the students break up a physics problem – say projectile motion – into simple easily understood steps that will logically lead the students to solve the problems in physics with understanding. This breaking up of a problem into simpler logical steps that leads up to the solution is what we define as ‘scaffolding’. We have found that this method works very well in classrooms the downside being that it takes much more time.

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It is a question mark whether it is worthwhile spending more time helping students master what they are expected to learn which may end with teaching less content, or is it better to just deliver the content in the stipulated time as is being done presently. These are questions that need more discussion especially when lack of mastery and true understanding is creating a gap between what the job market needs and the capability of our fresh graduates.

Methodology

We consider the methodology of scaffolding from the following two points of views:

1. Critical thinking based on asking right questions, analysis and narration.

2. Logical step by step progression.

We will demonstrate this with an example. Below is a typical question to test the understanding of projectile motion[1].

Problem 1: "A stone is thrown from the top of a building upward at an angle of 30.0° to the horizontal and with an initial speed of 20.0 m/s. If the height of the building is 45 m,

(a) How long does it take before the stone hits the ground?

(b) What is the speed of the stone just before it strikes the ground?"

A question of this nature should be analyzed thoroughly in the classroom so that students start to read questions carefully.

Critical Thinking:

Questions to be asked a priori-

a. In the above question the height of a building is given as 45 meters and the fact that a stone is thrown from the top of the building presumes that somebody is standing on top of the building and throwing the stone. Should we not consider the height of the person's fist at the moment the stone leaves his fist?

b. Nowhere in the question is it clarified that the ground on which the building is standing is horizontal!

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c. Should we expect the stone to come to rest when it hits the ground or should it bounce a few number of times before coming to rest? The latter possibility exists if the stone is round in shape.

d. What would happen if the ground where it lands has a downward slope?

e. What are the unstated assumptions in the question?

With the help of above questions we will restate the given problem accurately without any ambiguity. In the process, we will also get rid of the story form of the problem.

Restatement of the problem-

A person is standing/sitting on the top of a building. He throws a stone at an angle of 30.0° to the horizontal and with an initial speed of 20.0 m/s. The height of the building is 45 m. Ignore the vertical distance from the person's hand to the top of the building and assume the stone to be round in shape.

The stone rises to a certain height after being thrown and after some time falls on the ground taking a parabolic path throughout its journey. Assume that the ground on which it falls is flat. The stone most likely bounces a few times before it comes to a halt unless the ground is muddy wherein the stone can get embedded when it strikes. In any case, since the question is to find the speed of the stone and the time when the stone hits the ground for the first time, ignore the motion of the stone after it hits the ground for the first time.

We now give the narration and scaffolding for the above problem. By going through this part, *step by step the student will be able to solve the problem completely to the end.*

Narration and Scaffolding:

a. Narration- The first step would be to draw a sketch/graph and put all the available information in it. This is required to understand the information given vis-à-vis what needs to be determined. Also placing coordinate system helps one to start writing equations of motion with vector components of parameters like velocity, acceleration, displacement with 'plus' or 'minus' sign whichever is appropriate.

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Instruction- Sketch an appropriate diagram depicting the situation. Clearly mark x (horizontal) and y (vertical) axes and the origin. Mark ‘A’ as the starting point, ‘B’ as the highest point and ‘C’ as the point at which the stone hits the ground. Write coordinates of points A, B and C. Call the coordinates of point A as (x_0, y_0).

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b. Narration- The next step is to find out what the velocity components of the ball are in the horizontal and vertical direction. What do we mean by resolving vectors? Why do we resolve them?

Remember, the velocity vector makes an angle of 30° with the horizontal. The ball thrown at this angle will not go straight up. It will go to a certain height in a parabolic path after which the ball starts descending downwards again in a parabolic path before it hits the ground. This parabolic motion is considered as a superposition of two straight line motions one in the horizontal direction (along x-axis) and the other in the vertical direction (along y-axis). Point to be noted is that only gravitational acceleration acts on the ball in the vertical direction and no acceleration acts on the ball in the horizontal direction.

With this understanding, one can proceed to write equations of motion of the stone in x and y directions as the parabolic motion is a superposition of two straight line motions in x and y directions. The relevant equation of motion is $s = ut + \frac{1}{2}at^2$. In this equation one needs to take into account (i) displacement, (ii) velocity and (iii) acceleration with appropriate sign depending on the coordinate system you have chosen.

The displacement should be measured with respect to the starting point.

Now the velocity vector given in the problem is at 30° with the horizontal, which is neither in the x-direction nor in the y-direction. So one needs to find what is the effective velocity in x and y directions when the actual velocity is given at 30° with the horizontal (x-axis). The effective velocity of the stone along x and y directions can be found by resolving velocity vector along x and y directions. In other words, if you find projection of the velocity vector on x and y axes, what you get are the effective velocity vectors/velocity components along x and y directions. It is these velocity components that need to be plugged in the above equation of motion. You need to use your knowledge of trigonometry to write these components[2].

Remember, the velocity of the stone along x-axis remains unchanged and that along the y-axis changes due to gravitational acceleration.

Instruction- The stone is thrown at an angle of 30 degrees with a speed of 20 meters per second. Therefore, resolving the velocity vector into its horizontal and vertical components we get

$v_{x0} =$ ---

$v_{y0} =$ ---

Equation of motion for x and y distances are given by

$x - x_0 =$ --

$y - y_0$ = --

Eliminating t from the above two equations, one can write y in terms of x as:

$y =$ ---

The value (coordinate) of y when the stone hits the ground = -----------------------------------

$\therefore$ From x - y relation, the value of x at which the stone hits the ground

= --

Use equation of motion for x and find at what time, the stone will have the x value calculated in above step.

Using equation of motion for y, find out v_y at the time stone hits the ground (as calculated above).

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v_x at the time when the stone hits the ground = --------------------------------

Calculate $v = \sqrt{v_x^{\ 2} + v_y^{\ 2}}$ at the time when the stone hits the ground.

Answer -

The stone hits at the ground at ------------- seconds and its velocity at that time is ------------- (units ------).

Now we present a second problem based on projectile motion. This time we don't give scaffolding to the students. We expect the students to do critical thinking and ask right questions *a priori* to themselves. Then they may restate the problem without any ambiguity. This will then be followed by narration on self scaffolded steps to be taken to solve the problem.

Problem 2: "A monkey escapes from the zoo and climbs a tree. After failing to entice the monkey down, the zookeeper fires a tranquilizer dart directly at the monkey. The monkey lets go at the instant the dart leaves the gun. Show that the dart will always hit the monkey, provided that the dart reaches the monkey before he hits the ground and runs away."[3]

a. Is it possible that the dart will not hit the monkey? If so, under which conditions?

b. What happens if the dart is fired with less speed keeping the angle same? What happens if the dart is fired with more speed keeping the angle same?

c. Give a comment on the vertical distance from the ground where the dart hits the monkey in each of the above cases, as discussed in c.

d. Explain the situation if there is a moderate breeze parallel to ground in horizontal direction flowing with constant velocity. Does the breeze affect the maximum height achieved by the dart?

Expected understanding

For answering problem 2, the students have to understand that the dart follows projectile motion and the monkey follows a vertical straight line motion as a case of free fall. The solution requires understanding of two components of velocity v_x and v_y of the dart. They need to work out the time at which both of them will have same coordinates. The difference will come only in the vertical distance from the ground if the speed is changed. In case of breeze flowing in horizontal direction, it is again v_x that gets affected. Once again it can be shown that there will be difference in the vertical distance where the dart hits the monkey.

Analysis

The case presented above is just an example. There can be numerous ways to make them more interactive, meaningful and interesting. We didn't perform any statistical analysis but graded their answer sheets and also took feedback from them. Following are the observations that we made.

Some fast learners showed reluctance to undergo this trial at least the scaffolding part (Problem 1). Their reaction was so as they thought that they are capable to solve the problem in 3-4 lines much ahead of the class then, why explain in so many detailed steps which appeared mundane for them. However most of these students couldn't answer the subsequent problem and the critical thinking questions. Hardly any of them could get 100% score.

Most of the slow learners, who generally are numb at any problem posed to them, could start attempting the problem 1 with the help of scaffolding provided to them. Those who required our questions just as a support could make good progress and complete substantial part of the solution. However, to them as well, Problem 2 and the critical thinking questions were not possible to answer.

Overall, scaffolding and narration while solving such problems can make rote learning unnecessary. We expect that with enough practice the students will be able to do this kind of exercise for themselves having experienced the value of the approach. Further we expect, students learn to do critical thinking and narrative in their mind quickly and directly proceed to do calculations/analysis in a logical manner. Writing logical steps is also important because the evaluator needs to understand the clarity of the thought process of the student even if there is a mistake in the calculations.

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Recommendation

The instructional scaffolding approach should be implemented for all important concepts and problems based on them. The basic design of the scaffolding pertaining to classical mechanics can be as follows.

1. First students should be given time to imagine situation described in the problem and if possible should be asked to draw a sketch on it. While drawing sketch, many questions should surface if the students do critical thinking themselves. They can be asked to restate the problem as they have understood.
2. The narration then should start by small and basic steps which can give students enough time to dig out information like physical quantities involved units and differentiate as to which of them are given and which are to be obtained by solving the problem. They should be asked to define reference frame and the origin.
3. The questions that follow can then revoke their understanding of physics principle involved.
4. The students can then work out the numerical solution to the problem.
5. A handful of problems can then be given as exercises with scaffolding approach and slowly the scaffolds can be removed depending on the students' progress.
6. Once all the similar questions are answered by the students without scaffolds, the questions that can challenge their higher order thinking skills (HOTS) should be posed in the form of a new problem at advanced level.
7. Summary - After the scaffolded assignment is completed by each student independently, it can be graded. The student can then be given a tutorial sheet based on similar kind and twisted problems but without scaffolding. Their answers should be checked. Ideally, students should be taking up Tutorial assignments based on different concepts only after they achieve mastery in a given conceptual topic. Some deadline can be set up by the instructor for the submission of all the assignments (scaffolded as well as final tutorial sheet without scaffolding). The fast learners may be taking up new assignments earlier as compared to the slow learners but finally one can expect that each student would have achieved some level of mastery in each topic.

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We believe this approach should build confidence in weak students and if their perseverance and hard work is consistent, they can make remarkable progress in Physics course grades and in their overall understanding of the subject. The recommended systematic steps and the challenging questions asked during critical thinking process should also engage the fast learners as they realize that there is plenty of gaps for them to improve upon, understand and move deep ahead in the subject. These fast learners then can be guided to advanced level reference books and can be asked to solve higher level problems. They can be encouraged to do hands-on or computational projects based on the contents of the course. Finally, they can also be asked to review one research paper based on the contents of the course and made to explain their understanding in a written or oral presentation. They should also be motivated to do research project based on the contents of the course.

Although the recommendations mentioned above sound idealistic, if implemented properly, they may be real. The main point is that it cannot be one semester's task for the teacher and students. If the mastery on basic topics is achieved during high school education itself, it would be easier to develop learning approach at advanced level.

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