PROBLEM - BASED LEARNING IN BASIC PHYSICS - I

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In this article— first in the series of articles, we present a problem-based learning course that we have used successfully to build capacity of physics students. We present the learning objectives in different areas of basic physics and what each problem tries to achieve with its solution.

There is a criticism that at every stage of learning, success in examinations in present education scenario relied heavily on reproduction of material that the students had learned. No importance is given to development of necessary skills that can make students think like professionals. If carefully chosen as a part of learning process, problems can encourage the cultivation of a group of skills, which can be important constituent of the expertise of a professional. Problem-based learning is found to be a convenient method to teach subject/s. (Baden, 2000) and many experiments are being tried all over the world with a positive outcome. Problem-solving brings to bear essentially reasoning about the subject. Problem-solving is scaffolding/building up higher objectives of learning. As per Bloom (1980), these objectives are: comprehension, application, analysis and synthesis. Doing science itself in a way is problem-solving.

At a level of basic physics all problems chosen have to be well-defined and as Baden has described, in the subject of science, formal teaching has to precede problem-based learning. Apart from being used for testing, problems can become good instruments to help students construct their knowledge. This will also be in tune with NCF–2005 guidelines of 'promoting problem-skills, problem-solving abilities and applications of physics concepts/ content, useful in real life situations, for making physics learning more relevant, meaningful and interesting.

We have tried selecting our special problems for the course designed and following Redish (1994) termed them as **touchstone problems**.

Although we have used them in different sense than Redish.

By touchstone problem, we mean a problem which satisfies more than one of the following criteria:

(i) A problem which incorporates basic principle/s

(ii) A problem which is attractive enough or is rich in context

(iii) A problem which should be sufficiently difficult but not too difficult to put students off

(iv) A problem which should require steps that are not mechanical but involve some decision-making

(v) A problem which should have a reasonable goal

(vi) A problem which should guide students to comprehend the topic and/or application.

We have conducted such a problem-solving course covering topics from basic physics with similar problems. Most of the problems required one or more of the above-mentioned strategies to be used. The problems were of the level of standard textbook 'Fundamentals of Physics' by Halliday, Resnik and Walker (2004) and Young (2004). Most problems were chosen from the textbooks mentioned, competitive exams like JEE (Joint Entrance Exam for admission to Indian Institute of Technologies) and Physics Olympiads or equivalent. Source of some problem is unknown as authors have lost track of them over the period of time but found them to be indispensable. Some problems were specially designed as dictated by need.

The strategy we used to make students solve the problems can be called as constructivist, features of which are:

(i) Instructors should play a role of facilitator and help learner to get his or her own understanding of the concepts and let the learner play an active role in the learning process.

(ii) The learning environment should be designed to support (by making books available) and challenge through problems: touchstones and auxiliary (additional/smaller) and counter questions as well as guided intervention) the learner's thinking. This way learning becomes an active process where learner learns to discover principles, concepts and facts themselves.

(iii) Required instructor has culture, values and background to become an essential part of the interplay between learners and tasks in the shaping of meaning.

(iv) Students learn by building upon knowledge they already possess themselves and guided interventions correct errors, which creeps in their understanding.

(v) There should be enculturation. Students should be introduced to culture of the subject. In our case, students were introduced to culture of doing physics by solving problems.

(vi) Most importantly, there should be effective scaffolding. That is, students are not given answers to any questions, but have to be guided (using interventions like auxiliary problems, counter questions, cognitive conflicts) to converge to the answer themselves.

Based on how students work through, it can also be used for formative assessment (Mody, 2011). This way, students also get immediate feedback of their thinking and construction of knowledge as teacher uses her/his constructivist scaffolding. This is very much on par with the vision of National Focus Group on Examination Reforms (NCERT 2006a), which has noted. 'In the long-term (about a decade), we envision a vastly different system built upon entirely new foundations. This system would actually make the teacher the primary evaluator of students. This system would not be one-shot but continuous, would extend beyond the cognitive domain and beyond pen and paper; and, hopefully be seen by all not as a burden but as a tool for further learning. In this system, the primary role of boards would change radically – from direct testing at present to rigorous validation of school-based, teacher-based assessment. If any direct testing by boards were still to be needed it would be of a very different type – optional, open-book and on-demand. In this scheme emphasis is on students construction of knowledge and teacher can very much use it to assess students.

The problems on motion that we dealt with, are given as follows with the learning objectives and what each problem is expected to achieve along with solution. These problems can be used by teachers to teach finer aspects of concepts. Teacher may use any of the method they prefer: (i) could be done on board in the class, (ii) may be used as tutorials, (iii) may be given as home assignment, (iv) may be used as a tool to help students construct their own knowledge. We have used these problems as classroom work (as in (iv)) where teacher uses constructivist method as discussed above and described by Pradhan (2009a). As a result of such a course, we found students capacity increased and were ready to face challenges, which earlier they never thought of.

As per Downey (1967) , The core of good thinking is the ability to solve problems. The essence of problem-solving is the ability to learn in puzzling situations. Thus, in the school of these particular dreams, learning how to learn pervades what is taught, how it is taught, and the kind of place in which it is taught. The students gather around learning problems and study how they think and make conscious efforts to learn to think more effectively (as quoted in Joyce and Weil, 2005). Thus, we can achieve aim of education as per NCF-2005, which is to learn, how to learn and process of construction of knowledge through such problem-based method.

The methodology is discussed in detail with auxiliary problems by Pradhan (2009a). Results of our course were encouraging (Pradhan 2009b). Teachers have here responsibility to chose appropriate auxiliary problems, counter questions, etc... as per their strategy. We are presenting our course, based on problems as a series of articles starting with Mechanics— motion, with solution.

Mechanics

Learning Objectives

1. Understand motion without worrying about origin of motion, especially force.
2. Motion under constant acceleration, in one and two dimensions. Motion is always relative to an observer and hence how does

state of an observer changes description as we switch from one observer to another. In two dimensions there is a special class, which is circular motion.

3. Understanding motion: Linear and rotational (or equilibrium) in the light of Newton's Laws of Motion.
4. Understanding some of the interactions in the light of conservation principles (like momentum, energy, etc...). For example, the latest experiment in LHC (large Hadron Collider) also has these principles involved of course in much detail beyond the scope of this course. We have tried incorporating at a basic physics level.
5. To become familiar with mathematical structure of dealing with what is covered in above-mentioned points.

1. Kinematics in 1-D

An elevator ascends with an upward acceleration of 1.2 m/s^2 . At the instant when its upward speed is 2.4 m/s, a loose bolt drops from the ceiling of the elevator 2.75m from the floor. Calculate

(a) The time of flight of the bolt from the ceiling to the floor of the elevator.

(b) The displacement and the distance covered by the bolt during the free fall relative to the elevator shaft (Irodov 1988).

Tasks involved in this problem are:

1. To identify the reference frame.

   In this case students can work with either of two different frames: (1) elevator, and (2) ground based (what problem specifies as elevator shaft).

2. To specify value of velocity, acceleration and displacement using proper sign convention in each frame.
3. To recognise that time is same (Galilean invariant) in both the reference frames.
4. To be able to understand the difference between distance travelled and displacement.

This problem gives a thorough picture of use of Kinematical equations that are to be used for motion with constant accelerations.

The following problem can be used as an auxiliary problem to illustrate use of kinematical equations, sign convention and unit conversion.

A car moving on a straight highway with speed of 126 kmh^{-1} is bought to a stop within a distance of 200 m. What is the retardation of the car (assumed uniform), and how long does it take for the car to stop? [NCERT 2006b].

2. Projectile Motion

A ball starts falling with zero initial velocity on a smooth inclined plane forming an angle a with the horizontal. Having fallen the distance h, the ball rebounds elastically off the inclined plane. At what distance from the impact

point will the ball rebound second time? (Irodov, 1988).

Tasks involved in this problem are to:

1. use energy c onservation principle to find speed at the impact.
2. use momentum conservation principle and geometry to find direction of motion after impact.
3. understand meaning of elastic collision.

4. either break motion into two 1-D motion or treat it as a simple projectile motion problem.
5. make a decision about point of impact so that it can be incorporated into equations of projectile.

Smaller problems needed to do this problem need students to understand either how equations of projectile are used or how motion can be broken into two different 1-D motions.

The following auxiliary problem can be used to make students familiar with the use of equations that can be obtain for motion of a projectile.

A soccer player kicks a ball at an angle of 37° from the horizontal with an initial speed of 20 m/sec. Assuming that the ball moves in a vertical plane

(a) Find time (time of ascent) at which the ball reaches the highest point in its trajectory.

(b) How high does the ball go (maximum height reached)?

(c) At what instant the ball hits the ground (time of flight)?

(d) What is the horizontal range of the ball ?

(e) What is the velocity of the ball as it strikes the ground? [Take g = 10 m/s^2].

3. Relative Velocity

A motor boat with its engine on in a running river and blown over by a horizontal wind is observed to travel at 20 km/hr in a direction 53° East to North. The velocity of the boat with its engine on, in still water and blown over by the horizontal wind is 4 km/h eastward and the velocity of the boat with its engine on over the running river, in the absence of wind is 8 km/hr due South. Find

(a) The velocity of the boat in magnitude and direction, over still water in the absence of wind.

(b) The velocity of the wind in magnitude and direction. [Source: Unknown].

The following problem can be used as an auxiliary problem to illustrate use of Cartesian vectors to represent velocity in two dimensions and find relative velocity.

A girl riding a bicycle with a speed of 5 m/s towards north direction, observes rain falling vertically down. If she increases her speed to 10 m/s, rain appears to meet her at 45° to the vertical. What is the speed of the rain? In what direction does rain fall as observed by a ground-based observer? [NCERT 2009].

Tasks involved in this problem are

1. To find relative velocity, and
2. Rectangular resolution of vectors.

This problem was chosen as it involves basic idea of relative velocity and technique of using Cartesian representation of vectors.

Solutions to Touchstone Problems

1. Kinematics in 1-D

Inside the elevator

Initial speed $u = 0$,

Distance through which bolt falls $h = 2.75$ m

Acceleration of the bolt towards the floor

= acceleration of the elevator + acceleration due to gravity = $a + g$

= 11.0 m/s^2

$h = ut + ½ (a + g) t^2$ gives time of flight to the elevator floor = $\sqrt{1/2}$ = 0.707 s.

Outside the Elevator

u = 2.4 m/s and $a = g$

Time of flight being Galilean invariant remains same.

Hence bolt's displacement in time t is

$s = ut + ½ gt^2$ = - 0.753 m
(negative sign indicates downward displacement).

As seen from outside, bolt moves up and comes down (due to initial upward speed) crossing the starting point till it hits the floor. This upward motion upto the point when its speed becomes zero. Thus, $v^2 = u^2 + 2as$ gives H = 0.294 m.

Thus total distance travelled = $2H + s$ = 1.34 m.

2. Projectile Motion

Conservation of energy gives speed of impact

u = $\sqrt{2gh}$.

Since plane is inclined at an angle α to the horizontal and collision is perfectly elastic, the ball will be like a projectile launched at speed u and at an angle
$90 - 2\alpha$ to the horizontal. Taking point of impact to be origin, trajectory of the ball is given by

$y = (\tan\theta)x - \frac{g}{2u^2\cos^2\theta}x^2$, where x is horizontal distance and y is vertical distance. It hits the plane whose equation in the plane of the trajectory can be taken as $y = -x\tan\alpha$. The point of intersection (second impact if is at a distance L from first impact) on the plane ($L\cos\alpha$, $-L\sin\alpha$) substituted in equation of trajectory yields $L = 8h\sin\alpha$.

3. Relative Velocity

Taking west to east as x-direction, south to north as y-direction and taking $\mathbf{v}_b$ as boat speed with respect to still water, $\mathbf{v}_r$ river speed and $\mathbf{v}_w$ as wind speed, we have

$\mathbf{v}_b + \mathbf{v}_r + \mathbf{v}_w = 20 \cos 37\ \hat{i} + 20 \sin 37\ \hat{j}$

$\mathbf{v}_b + \mathbf{v}_w = 4\ \hat{i}$

$\mathbf{v}_b + \mathbf{v}_r = -8\ \hat{j}$

gives $\mathbf{v}_b = -12\ \hat{i} - 20\ \hat{j}$: 23.33 km/hr at 59°2' south of west

and $\mathbf{v}_w = 16\ \hat{i} + 20\ \hat{j}$: 25.61 km/hr at 51°21' north of east.

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