Educational Experiments in Problem-Based Learning for a Dynamics Course

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Abstract

It is generally agreed upon that problem-based learning (PBL) should enhance the educational experience of students over traditional class teaching. Within this spirit, the two authors have coordinated a year-long effort to introduce PBL in a required undergraduate Dynamics class. This paper describes specific ideas, and their associated advantages and disadvantages, which Dynamics teachers can possibly pursue to introduce PBL in their classrooms.

Introduction

The value of Problem-Based Learning (PBL) is well recognized in the education literature[1,2,3,4]. PBL is considered to be an ideal method for achieving educational learning objectives as set forth in Bloom's taxonomy[5]. This is all the more true in engineering and science education which typically relies on teaching difficult and abstract technical concepts that have very real-life applications and implications. It is natural then to expect that the in-depth analysis and study involved in typical PBL experiments or assignments should enhance the understanding of such concepts.

There are other methods in the area of mechanics education, besides PBL, which teachers rely on to enhance students' understanding of classroom concepts[6,7,8,9]. Most of these methods are currently computer-based as publishers and authors of undergraduate mechanics courses (e.g. statics, dynamics, and mechanics of materials) have bundled software with their textbooks. For example, some of the more advanced Dynamics software allows students to set-up parametric problems and watch real-time animations simulating physical behavior. There is no doubt that the use of such software in the teaching of mechanics courses has some value and advantages. Of course, the main disadvantage is that models are not like the real thing (i.e. they typically require a lot of simplifying assumptions on the geometry and boundary conditions of the problem) and some students learn more via hands-on experimentation than screen displays. This is due to the fact that different people have different learning styles[10]. Therefore, PBL typically involves some sort of real problem set-up and execution. In mechanics courses, this usually translates to assigning design project(s) to groups of students[11,12]. Such design projects are by definition open-ended and have no unique answer or solution. The students thus have to invoke their imagination and try to integrate a host of previous classes (i.e. previous knowledge) in order to solve the problem at hand. This form of learning is considered the ultimate form since it is a replica of real engineering practice. It is worth noting that PBL is already existent in many engineering curricula, most notably through senior design courses. It is not common, however, in introductory engineering classes, like Dynamics, which are typically lecture-based.

This paper discusses the efforts by the two authors at coordinating a PBL experiment, involving a design problem, in a junior-level Dynamics course at the University of New Mexico. The two authors taught the class in consecutive semesters and followed-up on the same experiment in both classes. This effort is in-line with recent departmental emphasis on integrating design into the engineering curriculum. The Department has recently instituted a five-course, four-year design sequence in its curriculum with the hope of graduating better engineers. Another benefit to the current PBL experiment, besides emphasizing to students the integration of design into engineering practice and education, was to give students an opportunity to use the 3D CAD software that they have learned in the year or two before taking Dynamics. While working on the project students also naturally developed communication skills and learned how to work in teams.

Description of The PBL Experiment

The PBL experiment consisted of asking student groups to design an apparatus of some sort that is capable of throwing a golf ball in the air for a horizontal distance of *at least* one meter such that it also passes through a 20cm hole in a vertical wood board. The hole center is one meter off the floor. The main objective of the experiment is thus to shoot the ball through the hole as long as the shot is made from a one meter horizontal stand off distance. The students were given access to an electronic balance and length-measuring tools (e.g. to measure the size and mass of a golf ball) whenever they requested them. They also had access to the machine shop in the case they needed to fabricate anything in-house. As it stood, the problem statement was pretty much open-ended and was thus expected to generate different apparatus designs. There was, however, one important constraint on the design. It had to be explained with equations and principles learned during class and during class *only*. In other words, if some students came up with a mechanism that worked but they did not understand how its mechanics worked, this would not translate into a good project grade for them. This was clearly stated to them before they started work on their projects.

Before putting together their projects, student groups met with the instructors to discuss their project plans. They were alerted to small details that they may have not been thinking about, or they were at least challenged to think about any assumptions that they were planning to make and verify such assumptions. This helped the students avoid pitfalls in their design down the road and hence reduced harm to their eventual project grade. Overall, such meetings were very important to force students to brainstorm about their projects and made the project experience more successful for both the students and the teachers. In addition, students were told from the very beginning that half of their project grade would depend on the successful building of an apparatus capable of consistently shooting the ball through the hole, and the other half would hinge on a report due on the project demonstration day. The report had to explain, in lengthy details, the analysis using Dynamics laws and equations that the students performed on their design concept or idea. The report would contain also any 3D CAD drawings or other geometry sketches that they have created. Ideally, the calculations should match reality. In most cases of course this does not happen and the students are therefore asked to explain any discrepancy between calculations in their reports and how their apparatus actually performed. They were also quizzed on this during the demonstration of their project.

In response to the assigned projects, students self-assembled into groups of three or four (without intervention from the instructor to influence the composition of groups). A total of 22 groups were formed (9 in one class and 13 in the other). A variety of designs were built by the students all of which had to be demonstrated during one day at the end of the semester. Digital images of the apparatus at work were taken on that day with a portable digital camera and some are shown in this paper. Some of the designs involved a sliding mechanism whereby the golf ball had to slide down a curve or path of some sort to generate linear momentum capable of flying the ball for a horizontal distance of at least one meter (see Figure 1 for an example). These designs relied on the fact that potential energy converted to kinetic energy during the downward slide of the ball. Other designs involved the use of a push or pull springs to drive the motion of the ball by converting the spring's potential energy into kinetic energy for the ball (Figure 2). Several other designs employed some sort of an impact mechanism to drive the ball's motion (see Figure 3 for one example). Other design concepts employed catapult-type construction. One such design used a stretched elastic rubber band to swing the golf bar upon release (Figure 4). Another catapult was built entirely out of play LEGO and naturally generated a lot of interest from both students and teachers (Figures 5-6). Lastly, there were two unique designs that were never repeated by other groups. One design involved a pipe shoot with a rotating wheel to drive ball motion out of the pipe. An electric drill drove the wheel and a cut was made through the plastic pipe to allow for wheel spinning and contact with the golf ball that is fed into one end of the pipe and shoots out through the other end (Figure 7). The other unique design involved an "air gun" whereby air was compressed into a chamber. This compressed air was then vented out through an orifice to push the golf ball in the gun's nozzle. The golf ball was put into a small vinyl drinking-cup that faced the air pressure as it vented out to the atmosphere (Figure 8). It might not be surprising to learn that two of the students involved in the air gun design served or are currently serving in the military. Before concluding this section, please refer to Table 1 which gives the percentages of the different design types chosen by the students in their projects.

Experiment Results and Discussion

As might have been predicted from both the problem statement and the actual design projects that the students embarked on, there are at least two fundamental Dynamics learning objectives or lessons that should be impacted by the project. The first one is the study of "projectile particle motion" since this is a good assumption for the flight of the golf ball over a length scale of at least one meter. The other one is the "work-energy equation" which is also known as "the principle of work and energy". This is so since all built mechanisms discussed above must rely on some conversion of work to kinetic energy to eventually propel the ball in the air. Of course there might be some other learning objectives impacted, for example "impact" analysis, in addition to these two which are common to all projects.

Overall, the design project generated a lot of interest and enthusiasm amongst the students. In a survey immediately after project demonstrations, the students were asked (1) if their participation in the project enhanced their understanding of "projectile particle motion" or not. If their answer was yes to (1) then was that a *significant* or *slight* enhancement. The other thing the students were asked was (2) whether the project enhanced their understanding of the "work-energy equation" or "the principle of work and energy" or not. Again, if yes to (2), they were asked to indicate whether it was a *significant* or *slight* enhancement. 100% of student respondents gave a yes answer to *both* (1) and (2) above which is obviously something the instructors were pleased to hear. In addition, 74% of students believed that the enhancement was *significant* on both (1) and (2), while the rest thought it was *slight*. Indeed, enhancing the student learning experience was a major drive for the PBL experiment and it seems to have achieved such a goal.

Although the experiment overall was perceived as a success based on the above discussion, there were still some learning issues that some students still missed. To illuminate, some of the groups that used a slide mechanism elected to ignore, without proper justification, the effects of friction between the sliding ball and the rail/slide in "the work-energy equation". This violates "the principle of work and energy" since in this principle the work done by *all* forces, including friction if it exists, should be accounted for. Indeed, this thing was emphasized to the students several times in class. As it turned out, neglecting friction resulted in *at least* a 20% error in the drop height calculation. The probable causes why students elected to neglect friction are: 1) they were not sure how to calculate it for a curved travel path, nor how to calculate the coefficient of friction, and probably thought it will be a time-consuming endeavor, 2) they see that neglecting friction is a common assumption in many problems in standard Dynamics textbooks. It is worth pointing out that calculating the coefficient of friction between the ball and the slide material is a relatively easy task. This can be accomplished by timing the distance traveled by the ball on a straight portion of the slide material and back calculating from that the coefficient of kinetic friction.

Most projects that utilized a spring, to give the ball the linear momentum it needed, did a good job trying to avoid interference with the spring once it is released from its compressed (or elongated) position. They also employed symmetry in loading the spring (i.e. they compressed or elongated the spring from two points that were 180^o apart). They also did a good job determining the spring constant before starting their final project assembly.

For the groups that selected an impact-type mechanism to put the ball in flight, students in general exhibited good understanding of the two different types of impact, namely "direct central impact" or "oblique central impact". They also did some preliminary experiments *prior to* project assembly to determine the "coefficient of restitution", which is a prime quantity in analyzing impact problems. The main difficulty with such type of apparatus design is that they are generally much more difficult to build than the above two mentioned mechanisms because they require stricter control on the exact impact location and speed. Anyone who played golf would appreciate this last statement.

The catapult design is also a hard design to build. The groups that choose such a design seem to have executed it well. A main issue in such design is to *precisely* determine the exact launch spot of the golf ball in the air (i.e. when the ball becomes airborne).

The lone design concept shown in Figure 7 suffered from inherent asymmetry associated with locating the spinning wheel on one side of the tube/ball. This translated into uncontrollable shots at times. Also, the "air gun" design shown in Figure 8 is also not recommended. Although this design always hit the ball inside the hole, it was overkill for what was required. The gun was able to shoot the ball for tens of feet (if not more) than for the just required 3 feet. Also, calculating air pressure force on the cup holding the golf ball in the nozzle was an extremely difficult task to accomplish due to gas expansion into the atmosphere.

Lessons Learned and Conclusions

There were quite a few lessons learned by the instructors from this PBL experiment:

1) The hardest part about the experiment was, in the first place, picking a good PBL problem that was relevant to the class material at hand. Some of the criteria that the author used in selecting a problem were: a) the design has to emphasize, or at least force the use of, concepts and equations learned in the classroom, b) the possible solution designs should be relatively simple to make or build, not costly in dollar amount, and not very time consuming.

2) The second thing learned was that the implementation of PBL takes a significant portion of the instructor's time.

3) The instructor needs to alert students to verify assumptions made in their design, or when they solve problems, before invoking such assumptions.

4) The student groups should be required to meet with the instructor at least once and sufficiently enough before the project deadline. The purpose of the meeting should be to discuss the design idea that they settled on in order to bring to their attention possible issues with their design and encourage their thought process on how to solve such perceivable problems. This is in an effort to avoid them pitfalls and make their project experience a successful one.

5) It is important that the instructor carries out a survey, or some sort of assessment, to try and quantify student learning or satisfaction with the PBL experiment. This obviously will help the instructor make future decisions and adjustments.

In conclusion thus, the authors' experiment with PBL in an engineering Dynamics class proved to be a good one. The authors thus would recommend such experiments to future Dynamics teachers who are looking for ways to enhance their students' grasp of difficult concepts. It is predicted that such experiments will instill more enthusiasm in students compared to traditional course delivery.

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Catapult	Spring	Impact	Slide	Other Designs
22.7	22.7	13.6	31.8	9.1

Table 1. Percentages of the different design types/categories chosen by the students for their projects.

Figure 1. One of the slide designs used to shoot the golf ball through a hole in a vertical wooden board. Notice the white golf ball in the air in this figure and others.

Figure 2. A design utilizing a compression spring tilted at an angle from the floor. The spring was enclosed inside a plastic tube.

Figure 3. A design that relied on the impact of a pendulum with the golf ball in order to shoot it in the air. In this picture, the pendulum (composed of a chamfered metallic solid cylinder attached to a rigid rod) is shown after it just hit the golf ball.

Figure 4. A design utilizing an elastic rubber band to catapult a golf ball. Before launch, the ball was seated in a smaller size hole at the end of the swinging catapult arm. Notice the student on the left-hand side catching the ball with his left hand (the ball is colored orange in this case).

Figure 5. A catapult design made entirely from LEGO. The golf ball is shown as it just passed through the hole.

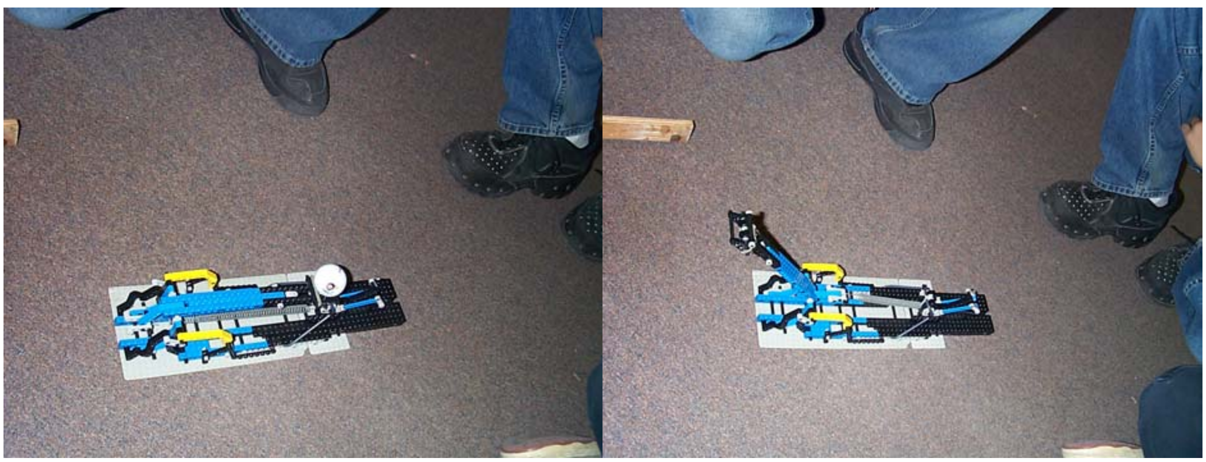

Figure 6. (a) The golf ball shown ready for launch from the LEGO catapult. (b) The catapult shown in the released configuration. The release energy comes off of a stretched spring placed underneath the catapult arm.

Figure 7. A design utilizing a motor-driven wheel to accelerate a golf ball through a tube shoot.

Figure 8. An air gun design ready to shoot. The ball is caught into a plastic trashcan immediately after it passes through the hole in the board.