Inquiry-Based Learning Activities in Dynamics

Jeffrey Georgette, Brian Self, James Widmann, Kathryn Bohn, Eric Wang*
California Polytechnic State University, San Luis Obispo/*University of Nevada, Reno

Abstract

The Inquiry-Based Learning Activity (IBLA) method was implemented in an undergraduate dynamics class to improve conceptual understanding. This was done through a rolling objects activity, in order to present students with the concepts of moment-of-inertia and work-energy. Students were evaluated with a Dynamics Concept Inventory (DCI), a quiz, a hands-on activity, and a final exam question. These activities were analyzed by the professor and teaching assistants to gain insight into student thinking and improve course outcomes and student learning success. Two implementations will be discussed: (a) a full IBLA where teams of 4-5 students manipulate the different objects, and (b) a demonstration mode in front of a class of 60 students.

Introduction

Students in higher education strive towards improving their factual knowledge, conceptual understanding, problem solving skills, and attitudes. Some argue that conceptual understanding is the most meaningful component among student effort. Educators have worked towards promoting conceptual understanding in the realm of college physics[1] and mathematics, although more work can be implemented in the engineering to realize learning gains. Student success can include conceptual understanding and pragmatic outcomes like increased knowledge and retention in programs[2]. Understanding concepts leads to growth throughout higher education, so care must be taken to guide the correct understanding of course material. If the student is to learn the course material, he/she must understand the fundamentals and be able to apply them in future contexts.

Active learning is used as a method to reach such aims. Student activity and engagement are key elements of active learning[2]. This contrasts with traditional lecture formats, where students passively receive information from the professor. Through inquiry based learning, students can actively engage by performing experiments and by learning in teams.

The reason for this study is to help students gain a greater understanding of dynamics concepts. Learning Dynamics requires mastering concepts, not simply memorizing facts or equations. Specifically, the concepts focused on in this study are moment-of-inertia and work-energy, which are essential to the course. Engineering concepts in Dynamics are not always intuitive to the student; since they cannot touch “energy” or feel “work” physically. Mass moment-of-inertia about a rotating axis not very intuitive, compared to mass translational inertia. Students often do not understand that bodies have both translational and rotational-kinetic energy. Unfortunately, students bring misconception into the learning environment and these must be worked on, to succeed in the future. According to the National Research Council, students can “parrot” answers on a test, repeating back phrases from lecture, and conceal their misconceptions, which may resurface weeks or months later[3]. These misconceptions must be addressed and corrected.

Work has been done in other science disciplines concerning conceptual understanding. In a study involving 6,000 students, Hake[4] showed that instruction that involved active learning and that emphasizing conceptual understanding resulted in much larger conceptual gains than traditional lecture-based approaches.

Students can work towards understanding such concepts through inquiry-based learning activities. The rolling objects IBLA was developed for a dynamics course for undergraduate engineers at Cal Poly San Luis Obispo, CA during fall 2012. We will also compare the IBLA results to the results from a demonstration-based activity in a large classroom at the University of Nevada, Reno.

Background

The purpose of an IBLA is to help students learn through inquiry and engagement by having reality act as the ‘authority’ instead of just the word of the professor. The professor can tell the students why something happens or will happen but this may not be as effective as letting the results of the physical experiment communicate the information. The IBLA method calls for students making a prediction of a physical situation followed by witnessing the result and reaching conclusions - similar to the scientific method. The students run their own experiments and thus take ownership of the learning process.

As shown in Figure 1, Laws et al.[1] show that using inquiry-based active learning instruction dramatically increases student performance on questions relating to force, acceleration, and velocity.

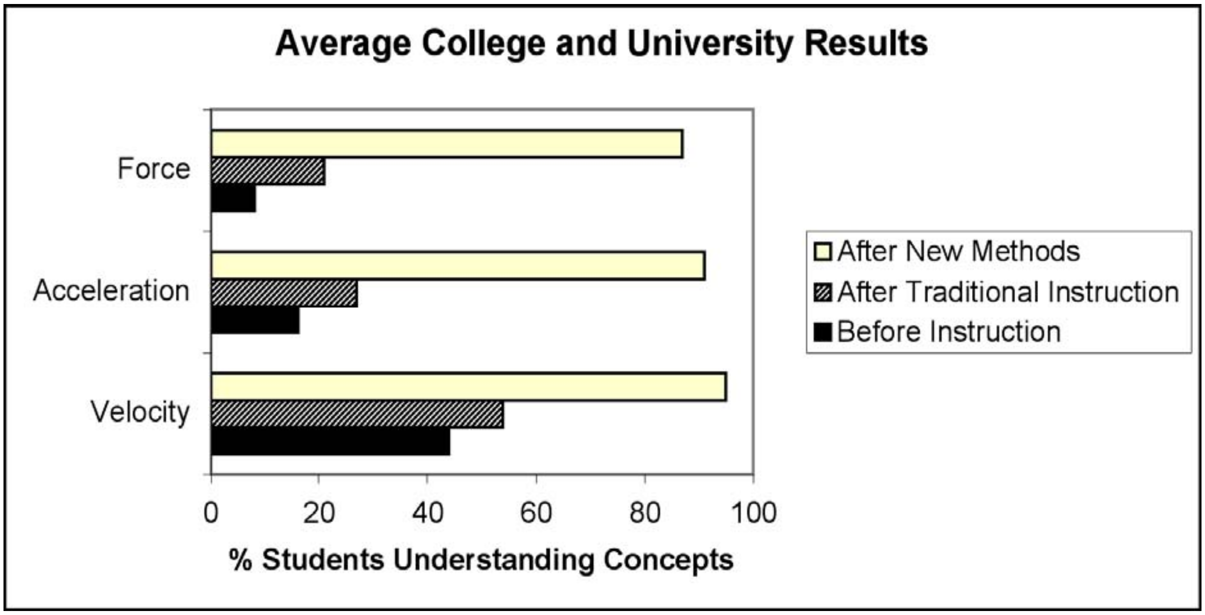

Figure 1. Active-engagement vs. traditional instruction for improving students' conceptual understanding of basic physics concepts (taken from Laws et al.,[1]).

Although the exact definition of inquiry-based instruction varies somewhat between different investigators, we will use the defining features offered by Laws et al.[1] and highlighted by Prince and Vigeant[5].

Table 1: Elements of Inquiry-Based Activity Modules

(a) Use peer instruction and collaborative work
(b) Use activity-based guided-inquiry curricular materials
(c) Use a learning cycle beginning with predictions
(d) Emphasize conceptual understanding
(e) Let the physical world be the authority
(f) Evaluate student understanding
(g) Make appropriate use of technology
(h) Begin with the specific and move to the general

Implementing the IBLA

Figure 2. The Cylinder/Pipe IBLA.

A hands-on experiment was used as the vehicle for implementing inquiry-based learning in the classroom. Students worked towards improving their conceptual understanding of rolling objects, including work-energy and mass moment of inertia. The students rolled objects down an inclined ramp and witnessed the behavior of objects with different masses, radii, and form (solid cylinder or pipe). The first object to finish the downhill race had the largest translational speed at the bottom of the ramp. The student teams rolled six different objects, with the form of either cylinder or hoop, and made of wood, PVC, aluminum, or steel (see Appendix F for a parts list), as seen in Figure 2.

As the students performed the experiments they filled out a worksheet (found in Appendix B). The students made a prediction before the test, recorded the results, and explained their conceptual understanding as they progressed. Through the worksheet, students confronted their predictions and later were able to create informed conclusions.

During the lab experience, the professor and teaching assistants oversee the activity alongside the undergraduate students. They are able to aid the students, ask them thought-provoking questions, and guide them towards the correct conceptual understandings in Dynamics. For example, if the students roll a given set of objects and had inconsistent results, the assistants would have them repeat the roll a few more times to make sure the correct conclusion was reached.

The Cylinder-Pipe IBLA addresses the effects of distribution of mass with the first exercise (big metal solid cylinder and the black metal pipe with same radius, length, and mass). The IBLA then goes on to explore different concepts of work and energy. This demonstrates to students that as long as there is rolling without slip, all solid homogeneous cylinders will have the same linear velocity at the end of the ramp, *independent of mass and radius*. Furthermore, all cylinders will always get to the bottom of the ramp before all pipes, regardless of the radius and mass. This is demonstrated by examining the work-energy equation: $T_1 + V_1 = T_2 + V_2$, where T and V are kinetic and potential energy, respectively. If the cylinder starts from rest, then $T_1 = 0$.

For a given ramp, the change in height will be same for all circular objects. Therefore, we can rewrite the equation as:

$$mgh = \frac{1}{2} I_G \omega^2 + \frac{1}{2} m v_G{}^2 \tag{1}$$

We now set the mass moment of inertia equal to cmr^2, where c is a scaling factor. For a thin ring, $c= 1$, and for a solid cylinder, $c= ½$. If we also substitute the roll without slip condition, $v_G= r\omega$, we obtain:

$$mgh = \frac{1}{2} cmr^2 \left(\frac{v_G^2}{r^2} \right) + \frac{1}{2} m v_G{}^2 \tag{2}$$

Solving for v_G, we see that the mass and the radius both cancel.

$$v = \sqrt{\frac{2gh}{1+c}} \tag{3}$$

Examining Eq (3), it can be seen that the linear velocity only depends on the mass moment of inertia factor, c. Therefore, a round object with a higher mass moment of inertia will get to the bottom of the ramp more slowly than an object with a smaller I_G. Many students realized that this really indicates a distribution of the translational and rotational kinetic energy of the objects. A cylinder will have greater translational energy than a pipe of identical radius and mass when released from identical locations on the ramp, and therefore will reach the bottom fastest.

Finally, after the IBLA a homework problem (see Appendix D) was assigned that asked the students to prove that a solid cylinder will always beat a pipe. This was followed by a problem where students use the work-energy equation to calculate velocities for a pipe, cylinder, and sphere at the bottom of a ramp.

Implementing the Rolling Objects Demonstration

At the University of Nevada, Reno (UNR) dynamics is a semester-long course taught in a traditional large, lecture style format (90-100 student is typical). In an effort to repair misconceptions concerning inertia, an in-class demonstration is conducted that lasts one full lecture period (50 minutes).

Personal response devices (a.k.a. “clickers”) are used daily to enhance student involvement. For this study, the clicker responses were used in lieu of a pre-test. It must be noted that students are allowed to discuss the question posed before answering, which confounds the results.

When prompted (via a PowerPoint slide) whether an aluminum or steel solid cylinder would have a higher speed at the bottom of a ramp, 37.4% of students indicated steel, 40.7% indicated aluminum, and 22.2% indicated they would have the same speed.

Likewise, when asked whether an aluminum cylinder or aluminum hoop would have a higher speed at the bottom of a ramp, 58.1% students chose the cylinder, 31.1% chose the hoop and, 10.8% indicated they would have the same speed.

After the initial questions were posed, the rest of the class period was devoted to demonstrating how different objected behaved as they rolled down a ramp. The equations discussed above were also covered followed by more demonstrations using cylinders and hoops with varying mass, radii and inertia.

Results

Table 2 shows (a) the pre- and post-DCI results of the rolling objects question, (b) the quiz results from the day before the IBLA, and (c) the results from the final exam question.

Table 2. Assessment of Cylinder IBLA and the Rolling Objects Demonstration: percentage of students answering the question correctly.

	DCI (Appendix)		Quiz (pre-IBLA) (Appendix)	Exam (Appendix)
	Pre	Post		
IBLA	31.3%	89.8%	43.4%	84.5%
Demo	58.1%	55.7%		

Students were tested on Dynamics concepts on an activity worksheet, the tally of coded responses can be seen in Table 3. Worksheet responses were broken up into an assortment of labels on the left hand column which were demonstrative of the concepts relating to moment-of-inertia and work-energy. The right column lists the percentage of students groups who reported the concept or statement.

Table 3. Categorizing student in-class worksheet responses

Concept or Statement written explicitly on worksheet by	Percent per student group out of total student groups
Moment of Inertia based upon mass distribution	38.8%
Moment of Inertia relates to rolling acceleration or translating velocity	67.4%
Potential Energy at top of ramp converts to Kinetic Energy at the bottom of ramp	75.5%
Kinetic energy distributes into linear and angular components	44.9%
Work-Energy equation	59.2%
Solid cylinders beat hoops, down ramp	2.1%
Either solid cylinders or pipes: roll with the same translational velocity	22.5%

The most stated concept was the conversion from potential to kinetic energy (75.5%); while the least stated concept by students was that solid cylinders beat hoops down the ramp (2.1%).

Subjective Assessment

Students were asked a number of questions on an end-of-course survey. They were able to express their opinions and rate course content. The first set of questions used a Likert scale to determine (a) if different course components helped the students learn the material and (b) students thought it was interesting and motivating. Averages for the responses are shown in Table 4, where 1= strongly disagree, 2= disagree, 3= neutral, 4= agree, and 5= strongly agree.

Table 4. Results from end of the course survey

The Cylinder/Pipe IBLA helped me learn the material.	The Cylinder/Pipe IBLA was interesting and motivating
4.38	4.12

Additionally, they were asked "When did the behavior of the different rolling cylinders finally make sense to you (e.g., in the middle of the activity, after talking to your team about it, after it was discussed in class, when you took the quiz, after you saw the quiz solution, it still doesn't make sense...)?". Responses were coded and are tabulated in Table 5, helps the professor to pinpoint when the students experienced the "aha" moment and understood the course concepts.

Table 5. Student responses as to when they understood the concepts in the IBLA.

Concept	**Quantity of response**
Understood beforehand	10
During/after quiz	2
During activity	52
Talking with team	36
After activity	7
Discussion in class	19
Studying it later	11
After homework	22
Still confused	7

Video footage was taken to witness student learning progress during the activity. Through the recordings, we could investigate students' justifications and thought processes while answering the different prompts.

From the video footage one group of students began to see a trend in the outcomes. For example, one student reported that "mass and radius did not affect rolling behavior." Furthermore, by the end of the worksheet they started to make the correct predictions, such that "all pipes would roll the same." One group compared the gravity force from a large cylinder to the large moment of inertia it possessed. One group mentioned, "Gravity force gets bigger with cylinder/pipe mass, but longer to accelerate." One group stated their "predictions were wrong", which shows they were perceptive of their previously held misconceptions, which can later be repaired with the correct conclusions. Most groups managed to stayed on task - usually one person in the group acted as the writer, while another acted as the lead "roller."

One misconception was that the ratio of two objects' moments of inertia was equivalent to the ratio of their radius or the ratio of their mass. This was written as a justification for predictions of the rolling behavior of two solid cylinders of different radius and mass (for example, some guessed that the hollow pipe would beat the solid cylinder). Some groups felt the time crunch and sought to finish the activity quickly and write something down in paper, even if they were not fully sure of their results

Discussion of the results

The main focus of this study was to impart conceptual understanding and repair misconceptions from Dynamics. From the results, more than 80% of the students answered the post-DCI question and final exam correctly, while the average quiz score was around 40%.

Through the hands-on activity the majority of students reached correct conclusions from the rolling behavior of the objects. Unfortunately, a small difference in the starting position can change the final outcome so that two solid cylinders may not reach the bottom of the ramp at exactly the same time. Interestingly, students will cling to their previously held misconceptions even if there is only a slight difference in velocities at the bottom (e.g., a steel cylinder just barely beats a wooden cylinder). To minimize starting effects, we recommend a shallow ramp angle (see Figure 2) and the construction of some type of starting gate,

From the coded responses in table 2, understanding of the lower percentage scoring areas (example: solid cylinders always beat hoops down ramp) could be improved through new methods or more effort in current methods. Although moment-of-inertia is an important concept it was only shown by 38% in student's worksheet responses, there is room for improvement. Another concept, work-energy equation, an important dynamics relationship, was stated on 59.2% of group worksheets. Both of these topics were covered on the follow-up homework assignment. Emphasis could be added to promote such concepts and steer the student in the right direction towards the right answer. This could be done by a question explicitly probing this idea or by more coaching to direct the student. Such questions would elicit students' held misconceptions, which can then be repaired.

It is unclear if the students' explicit responses represent their true understanding. Perhaps only a minority of the group decided what to write down, and understanding could be deeper than what was written on the worksheets. Perhaps the format of the worksheet influenced learning outcomes. For example, some of the concepts were asked for explicitly in the question prompt, while others were not. We hoped that the students would reach the right conclusion for each prompt and think critically.

From the survey represented in table 5, performing the physical activity proved to be a significant influence in understanding of the subject (52 responses) as well as talking with teammates (36 responses). One teaching assistant noted when students had others to collaborate with, they did well. Survey comments show that student understanding grew because of the activity.

A starter gate will be constructed. Also the worksheet will be modified to emphasize topics that were not understood as well as others. This will be implemented on future iterations of the activity in upcoming classes.

Comparison of IBLA to monstration

As can be seen in Table 2, the students who participated in the IBLA scored considerably higher on the DCI post question (Appendix A) than those who witnessed the demonstration. Although this cannot be attributed totally to the IBLA, it does suggest that active participation in the activity and continued testing and discussion of different rolling objects may have a large effect on student understanding. The follow-on homework assignment may also play a large role in the outcome – asking students to make calculations after doing the physical activity could have strongly reinforced the IBLA. A comparison of the IBLA and demonstration mode certainly bears additional investigation.

Conclusions

The first implementation of the IBLA was largely successful. The students found the activity motivational and helpful to their learning. Student scores on a relevant DCI question were nearly three times higher than at the beginning of the course, and 44% higher than a control group where a similar demonstration was provided. The IBLA forced students to make predictions, directly confront their misconceptions, and formulate new conceptual frameworks to explain the behavior of the rolling objects. It is hypothesized that the follow-on homework assignment helped to solidify this new conceptual framework and improved student understanding of mass moments of inertia and the principles of work and energy.

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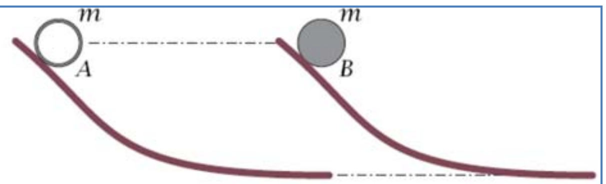
Appendix A: DCI Question

The two objects in the figure at the right are released from rest at the position shown and roll without slipping down identical hills. Both objects have the same mass m and same outer radius. Object A is a thin hoop whose mass is concentrated in its outer edge. Object B is a uniform solid cylinder. Neglecting air resistance, how do the speeds of the two objects compare when they reach the bottom of their respective hills?



(a) A and B will have the same speed.

(b) The speed of A will be greater than that of B.

(c) The speed of B will be greater than that of A.

(d) Knowledge of the friction forces is required to answer the question.

(e) Knowledge of the shape of the cross-section of the thin hoop is required to answer the question.

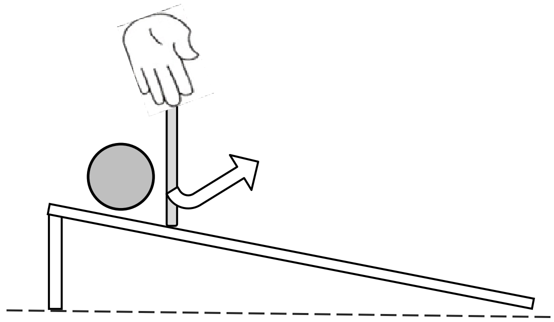
Appendix B: Cylinder-Pipe IBLA Worksheet

Cylinder vs Pipe Laboratory

Setup

Create an incline with the ramp with a height of several inches using a book or steps.

Experiment



Place the rolling objects close to the top of the ramp and side by side. Create a ‘starting gate’ with the clipboard. To initiate the race, flip up the clipboard with both hands. When the objects roll to the bottom of the ramp catch them or use a cushion to stop them. Run the following scenarios and respond to the prompts.

<u>Exercises</u>

- Roll the **big metal solid cylinder** and the **black metal pipe.** (Same radius, length, and mass). State your prediction. State the post-race result. How do you explain the race result using principles of Dynamics?

- Next, roll the **small metal solid cylinder** and the **wood solid cylinder**. (Same radius and length, but different mass).
  State your prediction and state the post-race result. How does mass influence rolling behavior?

- Roll the **big metal solid cylinder** and **wood solid cylinder**. (Same length and shape, different mass and radius).
  State your prediction and state the post-race result. How do the cylinders compare to each other?

- Roll the **small PVC pipe** and **big PVC pipe** and **grey metal pipe**. (Same length and shape, different radius and mass).
  State your prediction and state the post-race result. What is the rolling behavior of pipes?

- Which has bigger Kinetic Energy when it reaches the bottom, the *big metal solid cylinder* or *black metal pipe*? (same mass and radius)

- Which has bigger Kinetic Energy when it reaches the bottom, the small metal solid cylinder or the wood solid cylinder, or big metal solid cylinder?

Appendix C: Quiz Question Before the Cylinder/Pipe IBLA

In the picture above, the cylinder (A) and the pipe (B) above have the same outer radius and the same mass. If they are released from rest and roll without slipping down identical ramps, which of the following statements is true?

a) The cylinder A will get to the bottom of the ramp first

b) The pipe B will get to the bottom of the ramp first

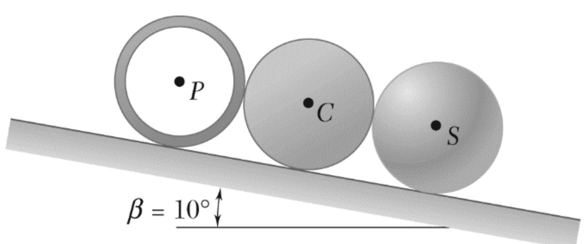
c) The cylinder A and the pipe B will get to the bottom of the ramp at the same time

d) There is not enough information to tell

Appendix D: Homework Due After the Cylinder/Pipe IBLA

1. Use the Work-Energy Equation to show that a cylinder will always reach the bottom of the ramp faster than a pipe with a small thickness, ***independent of mass or radius***.

2. A homogeneous sphere S, a uniform cylinder C, and a thin pipe P are each released from rest on the incline shown. Knowing that all three objects roll without slipping. Each has the same outer radius of 10 cm and the same mass of 1 kg. After rolling for 3 meters, calculate the linear velocity of each rolling object.



Appendix E: Final Exam Problem Assessing the Cylinder/Pipe IBLA

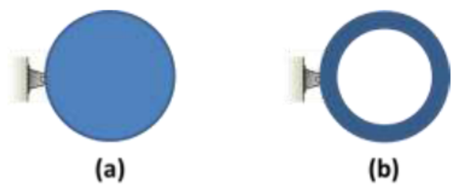
The thin disk (a) and ring (b) both have the same mass and radius. They are both released from rest in the horizontal position shown. Which will have the higher angular acceleration when they are released?

a. The thin disk (a) will have the higher angular acceleration

b. The ring (b) will have the higher angular acceleration

c. The disk and ring will have the same angular accelerations

d. Not enough information to tell



Appendix F: Activity parts list

Big solid aluminum cylinder	Outside radius: 1.75 inch	Mass: 2.7 pound	Length: 2.9 inch	Aluminum 6061	McMaster: 8974K89
Small solid aluminum cylinder	Outside radius: 2 inch		Length: 3 inch	Aluminum	Metal supply
Black metal pipe	Outside radius 1.75 inch, inside radius 1.45 inch. Wall thickness: 0.3 inch	Mass: 2.7 pound	Length: 3.15 inch	Steel unthreaded pipe size 3	McMaster: 7972K322
Grey stainless steel pipe				PVC	Scrap
Large PVC pipe	Outside radius: 6.25 inch		Length: 3 inch	PVC	Home depot
Small PVC pipe	Outside radius: 2 inch		Length: 3 inch	PVC	Home depot
Wood solid cylinder	Outside radius: 2 inch		Length: 3 inch	wood	Home depot