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Demo or Hands-on? A Crossover Study on the Most Effective Implementation Strategy for Inquir–Based Learning Activities

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Demo or Hands-on? A Cross-Over Study on the Most Effective Implementation Strategy for Inquiry-Based Learning

Abstract

During the past five years, our team has developed a number of hands-on inquiry-based learning activities (IBLAs). These activities follow a predict-observe-explain cycle, where students are first presented a physical scenario that they must individually evaluate. For example, in the Cylinder IBLA, students are asked to individually predict what will reach the bottom of a ramp more quickly, a pipe or a solid cylinder. Students then discuss the scenario in teams, and subsequently observe the actual "race". After the observation, the student teams try to explain the results using a guiding worksheet. The first scenario is then discussed with the instructor, and additional variations of the scenario are presented.

As we developed the activities, we allowed each student team to handle the different artefacts and perform the "experiments". Our current research investigates the differences between having the students perform the hands-on experiments themselves and having the instructor perform a demonstration in front of the room. Two instructors, A and B, teaching from the same syllabus, same course notes, and with a very similar active teaching approach, used both the Pulley IBLA and the Rolling Cylinder IBLA in their class sections. Instructor A did the Pulley IBLA using a hands-on student approach, while Instructor B did the IBLA as a professor-led demonstration. For the Cylinder IBLA, they switched; Instructor A did the demo while Instructor B did the hands-on. We compared results from targeted questions on the Dynamics Concept Inventory (DCI) between the two groups, and also compared these results with other instructors who do not use the IBLAs and who teach in a more traditional lecture-based approach.

For the Pulley IBLA, DCI scores on the targeted questions were: Hands-On [95.4%], Demo [93.9%], Control [70.8%]; for the Cylinder IBLA, the results were Hands-On [84.8%], Demo [86.2%], Control [61.2%]. There was no difference between the Hands-On and Demo groups, but both significantly outperformed the control group. Students also filled out a subjective survey, which showed little preference for the Hands-On versus Demo modalities, and that both modalities helped with their learning.

Introduction and Background

Inquiry Based Learning Activities (IBLAs) are emerging as effective techniques to increase conceptual understanding in Heat Transfer[1, 2] as well as in Dynamics[3]. The term "inquiry" has been used extensively in science education, and many variations on the exact definition of inquiry based instruction exist. The NRC[4] identifies five critical features of inquiry that extend across all K-12 levels:

1. Learners are engaged by scientifically oriented questions.
2. Learners give priority to evidence, which allows them to develop and evaluate explanations that address scientifically oriented questions.
3. Learners formulate explanations from evidence to address scientifically oriented questions.

4. Learners evaluate their explanations in light of alternative explanations, particularly those reflecting scientific understanding.
5. Learners communicate and justify their proposed explanations.

Minner et al[5] performed a meta-analysis of 138 studies to examine the impact of inquiry based instruction on K-12 student science conceptual understanding. They found "a clear, positive trend favoring inquiry-based instructional practices, particularly instruction that emphasizes student active thinking and drawing conclusions from data."

Despite this strong evidence of effectiveness in science education, reports on using inquiry activities in engineering education appear to be quite limited. Prince et al.[1] have had success in implementing IBLAs in Chemical Engineering, particularly to look at heat, energy, and thermodynamics. Their work is based on that of Laws et al.[6] and on Workshop Physics (http://physics.dickinson.edu), which defines the elements of IBLAs as summarized in Table 1.

Table 1. Elements of Inquiry Based Learning Activities.

(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

Our IBLAs follow a predict-observe-explain cycle, where students are confronted by a series of physical scenarios. For each scenario, the students are first required to make individual predictions about the physical phenomena of interest, discuss their predictions with a group of 3-4 students, observe the system experimentally, and then discuss and explain the experimental results on a team worksheet. At specific instances, direct instruction is incorporated to make sure students are applying appropriate scientific principles (Figure 1). With IBLAs, the focus is on conceptual understanding through the integration of hands-on activities in a cycle of predictions, observations, and explanations. In most of the initial scenarios, we hope to create cognitive conflict – challenging the students' current conceptual framework. By observing the experimental results, the physical world becomes the authority rather than the word of the instructor.

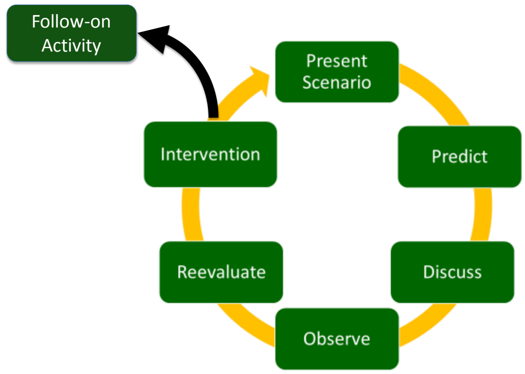

Figure 1. IBLA Learning cycle.

Dynamics IBLAs

Undergraduate Dynamics is typically the first truly challenging course in the engineering curriculum, and many of the topics covered are in direct conflict with student perceptions of the world around them (e.g., there is no such thing as centrifugal force). To date we have developed five different IBLAs, as described in Table 2. Each of the IBLAs targets specific principles that students typically find to be difficult. The Pulley and the Impact Pendulum IBLAs are run in the first half of the course when we cover particle dynamics, the rigid body Spool and the Rolling Cylinders IBLAs take place in the second half of the course, and the Gyroscope IBLA is part of our follow-on course *Intermediate Dynamics* (but might be included at the end of a semester course that includes three-dimensional kinetics). Here, we discuss results from the Pulley IBLA and the Rolling Cylinder IBLA.

Table 2. IBLAs and their targeted principles.

IBLA	Targeted principle(s)
Pulley	Particle Newton's Second Law
Impact Pendulum	Particle Work and Energy; Impulse and Momentum
Spools	Relationships between (a) net force and linear acceleration; (b) net moment and angular acceleration; (c) linear and angular accelerations
Rolling Cylinders	Effect of mass distribution on rolling; Rigid body work and energy.
Gyroscope	Three-dimensional kinetics; gyroscopic moments; action and reaction

Pulley IBLA

The Pulley IBLA is based on the Atwood machine[7], which has long been used in physics and dynamics courses to help teach Newton's second law[8, 9]. As shown in Figure 2, two different scenarios are presented, side-by-side, and students are asked to predict which system will have the greatest acceleration – A or B. Unfortunately we have been unable to develop an inexpensive version of Case 5, so in this case the results are simply explained by the professor.

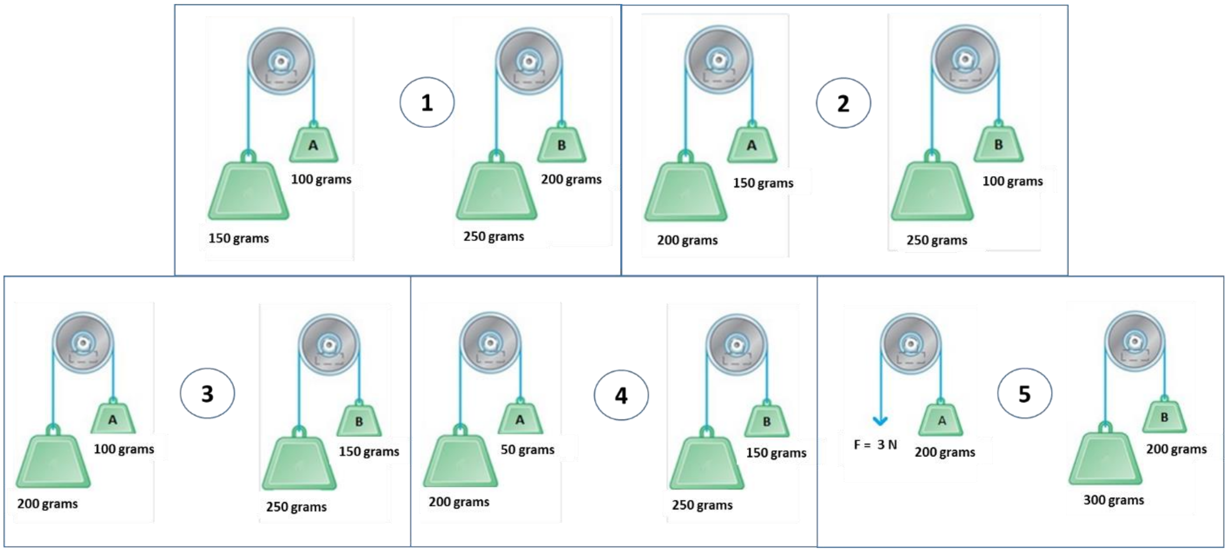

Figure 2. Five different scenarios in the Mass Pulley IBLA.

Rolling Cylinders IBLA

The Rolling Cylinders IBLA focuses on the relationship between translational and rotational kinetic energies and the effect of mass distribution on a rolling object. Comparing how the objects show in Figure 3 roll down a ramp provides compelling visual evidence of dynamic principles. By following our predict-observe-explain cycle along with the benefits of collaborative learning, we feel that our IBLAs offer unique learning experiences in dynamics.

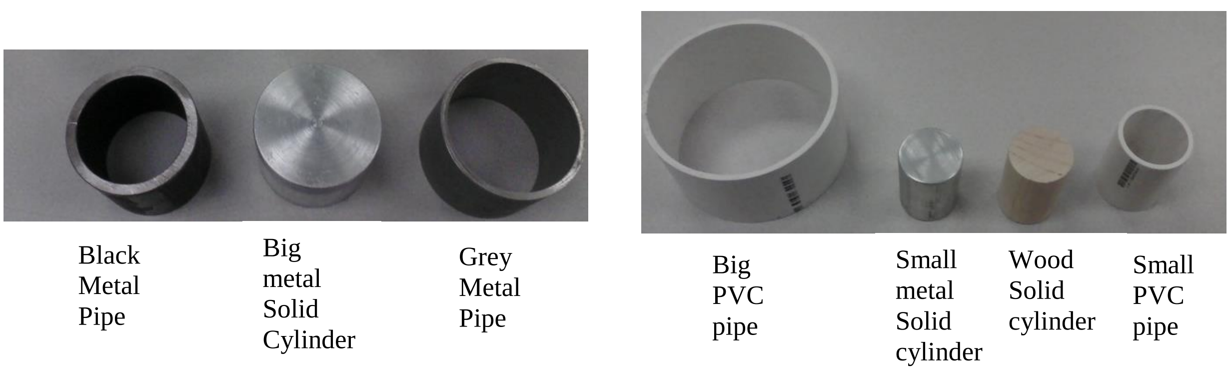

Figure 3. Test objects for the Rolling Cylinders IBLA.

The specific "races" and their targeted concepts are provided in Table 3, and a picture of the students testing different objects is shown in Figure 4.

Table 3. Cases and targeted concepts for the Rolling Cylinders IBLA.

Case	Targeted concept
Big metal cylinder vs Black metal pipe (same m, same R, different shape)	Distribution of mass – larger mass moment of inertia results in smaller translational velocity
Small metal solid cylinder vs Big metal solid cylinder (different m and R, same shape)	Work energy principles – the translational velocity is independent of mass and outer radius when the shape is the same
Small metal solid cylinder vs Black metal pipe (different m, R and shape)	Work energy principles and effect of mass distribution – the solid cylinder always beats the pipe
Small PVC pipe vs Big PVC pipe vs Grey metal pipe	Rolling object with the same shape will tie, regardless of mass and outer radius

Cross-Over Study

For the current study, two different instructors (A and B) taught the dynamics course at the same time of day. For the Pulley IBLA, Instructor A provided physical artefacts to each of the eighteen teams who participated. Instructor B used a single pulley setup and ran the "experiment" as a demonstration at the front of the room. Both classes ran through the predict-observe-explain cycle shown in Figure 1, and timers were utilized to try to keep the time on task as similar as possible. Naturally, having the students manipulate the artefacts themselves, change around the different masses, and run the races took a bit more time than having the instructor simply demonstrate the "races", potentially leaving more time for the instructor intervention and explanation of results.

Figure 4. Students doing Rolling Cylinders IBLA.

For the Rolling Cylinders IBLA, the roles of Instructor A and B were reversed – now Instructor A performed the IBLA in "demonstration mode" while the students in Instructor B's class were given the different artefacts with which to experiment. As for the Pulley IBLA, the predict-observe-explain cycle was utilized, and students made individual predictions, discussed their predictions in groups, observed the behavior of the cylinders, and then tried to explain their results on a team worksheet.

Methods and Results

Students filled out a subjective survey after each IBLA and were asked a number of questions, including a Likert scale question "This activity helped me learn dynamics" and a second question on if they preferred instructor demonstrations or doing the activities "hands-on". Results from each of these surveys are show in Figures 5 and 6. The students were asked this question immediately after each activity was performed.

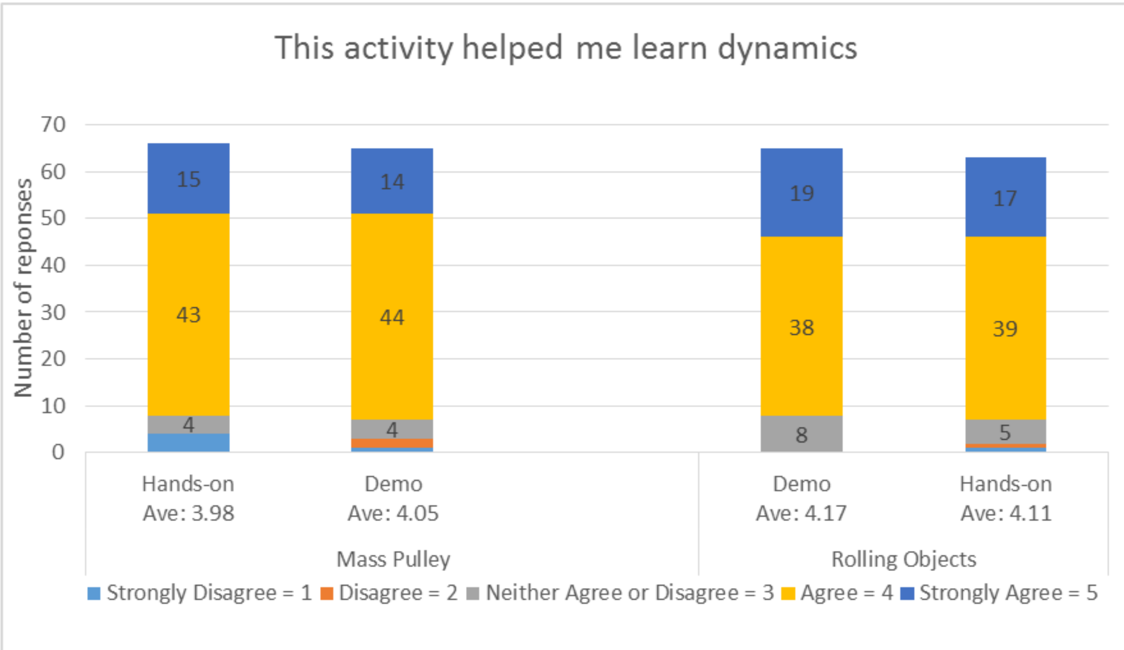

Figure 5. Student survey responses on if the IBLAs helped their learning.

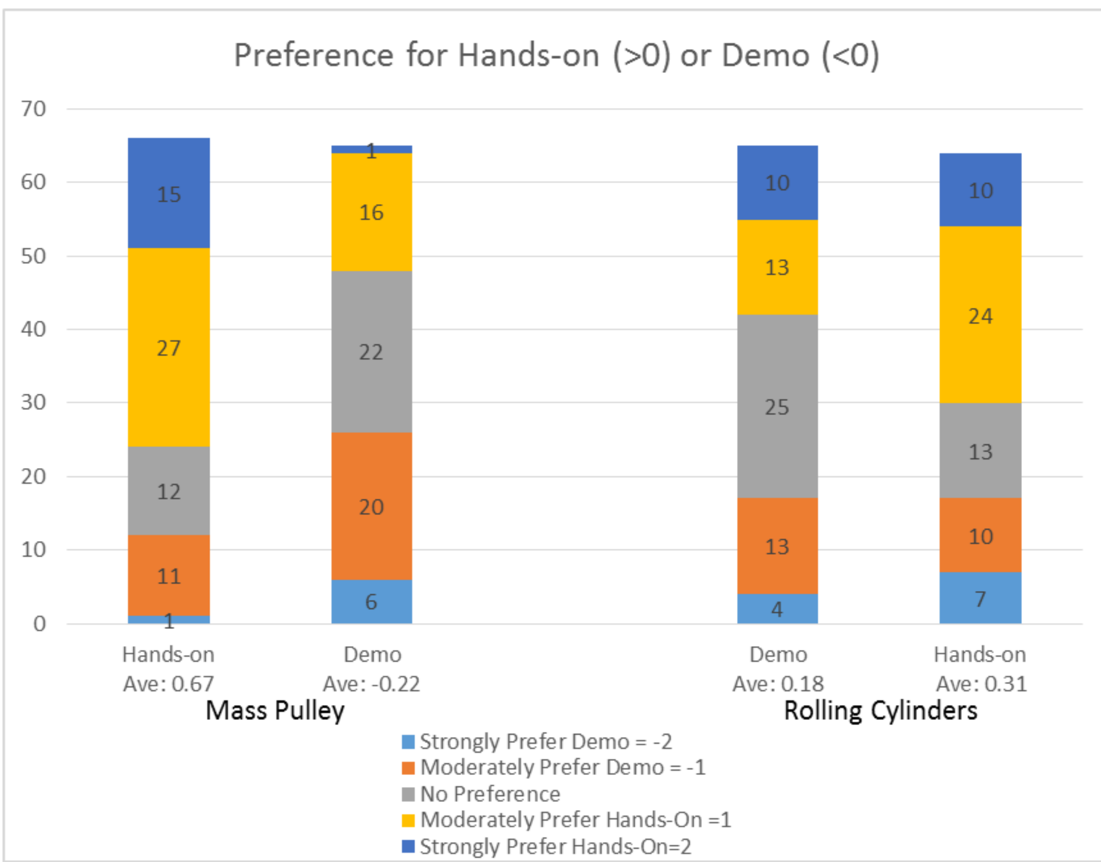

Figure 6. Survey responses on preference for Hands-On versus Demo. The titles underneath each bar indicated if the student was in the Hands-on or Demo group for that particular IBLA.

Students also took the Dynamics Concept Inventory after the course was completed. Scores on two targeted concept questions dealing with the Mass Pulley and the Rolling Cylinders IBLAs were collected for the hands-on, the demo-based, as well as several others sections of dynamics that did not use the IBLAs. Results are provided in Figure 7.

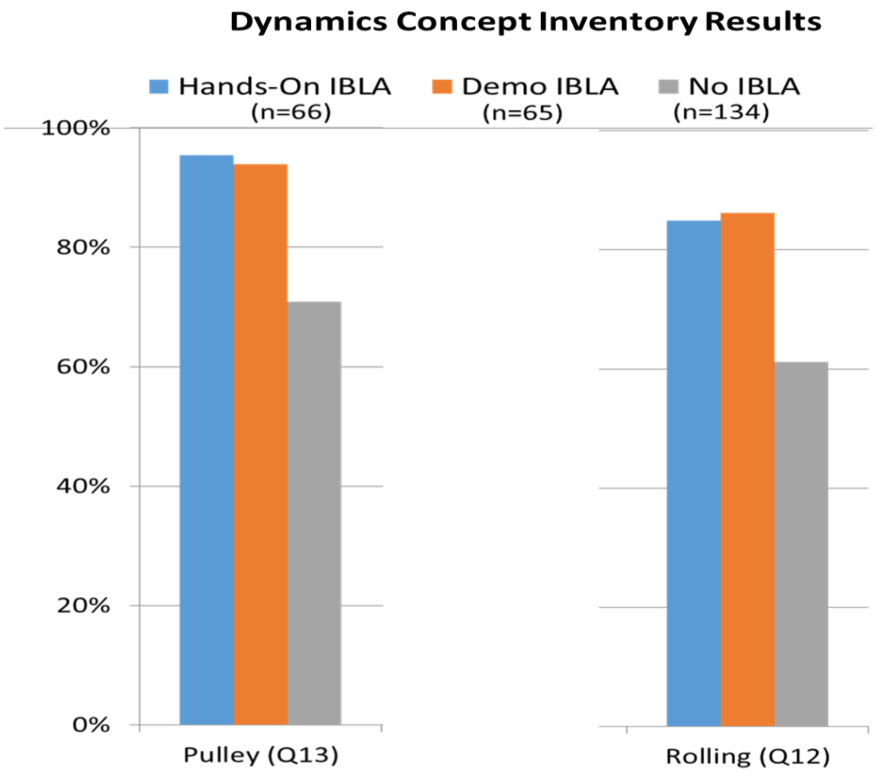

Figure 7. DCI scores on targeted concepts.

Discussion

Although we had anticipated that the students would prefer the hands-on version of the activity, this did not end up being the case. Although not statistically significant, students thought they learned slightly more from the demo versions of both cases – this may be due to the fact that the instructor provided a bit more guidance and explanation as they performed the demo and stated the results of the "race". For the Mass-Pulley IBLA, those who were in the Hands-On section preferred the hands-on implementation, while those in the Demo section preferred the demonstration. These results were somewhat similar for the Rolling Cylinders, although even the Demo section slightly preferred the hands-on implementation.

The DCI results were also quite interesting. Although there was no significant difference between the Hands-On and Demo sections, the two were both significantly higher than the scores from the non-IBLA sections.

Conclusions

When deciding between a demonstration and hands-on session, an instructor must consider many different aspects of their classroom – number of students and required test setups, availability of resources, student engagement, and teaching to the many different preferences of our students. Preliminary results from our cross-over study show no difference in learning gains between the hands-on and demonstration modes of the IBLAs, but do show strong learning gains over non-IBLA sections of the course. Although our results were inconclusive regarding the Demo vs Hands-On preference, it is apparent that many students do in fact prefer the Hands-On implementation of the IBLA. It might be best to simply vary how the IBLAs are done, so that preferences of all students are met throughout the timing of the course.

Acknowledgements

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