ASEE AMERICAN SOCIETY FOR ENGINEERING EDUCATION

2017 Pacific Southwest Section
Meeting: Tempe, Arizona Apr 20 Paper ID #20702

Student Self-Explanation When Solving a Rigid Body Kinetics Concept Question

Julia Roche, California Polytechnic State University, San Luis Obispo

I am currently pursuing my Bachelor's of Science in Mechanical Engineering at Cal Poly San Luis Obispo. My interests span a variety of things including engineering outreach, hands-on activities, machine shop, pottery, running, and riding my bike! I will be entering the medical device field after graduation in June 2017.

Dr. Brian P. Self, California Polytechnic State University, San Luis Obispo

Brian Self obtained his B.S. and M.S. degrees in Engineering Mechanics from Virginia Tech, and his Ph.D. in Bioengineering from the University of Utah. He worked in the Air Force Research Laboratories before teaching at the U.S. Air Force Academy for seven years. Brian has taught in the Mechanical Engineering Department at Cal Poly, San Luis Obispo since 2006. During the 2011-2012 academic year he participated in a professor exchange, teaching at the Munich University of Applied Sciences. His engineering education interests include collaborating on the Dynamics Concept Inventory, developing model-eliciting activities in mechanical engineering courses, inquiry-based learning in mechanics, and design projects to help promote adapted physical activities. Other professional interests include aviation physiology and biomechanics.

Dr. James M Widmann, California Polytechnic State University, San Luis Obispo

Jim Widmann is a professor of mechanical engineering at California Polytechnic State University, San Luis Obispo. He received his Ph.D. in 1994 from Stanford University and has served as a Fulbright Scholar at Kathmandu University it Nepal. At Cal Poly, he coordinates the departments industry sponsored senior project class and teaches mechanics and design courses. He also conducts research in the areas of creative design, machine design, fluid power control, and engineering education.

Student Self-Explanation When Solving a Rigid Body Kinetics Concept Question

Julia Roche, Brian P. Self, Jim Widmann
California Polytechnic State University, San Luis Obispo, CA

Abstract

The purpose of this ongoing research is to increase conceptual understanding of dynamics using Instructional-Based Learning Activities (IBLAs). IBLAs allow students to participate in hands-on activities where they are presented with a physical scenario that challenges their conceptual understanding of physics principles. Students first make individual predictions and then discuss their predictions with their peers (and "vote" again). They test their conceptions using a physical artifact (although simulations could be used for this), letting the physical world be the authority rather than just the word of the instructor. The teams then fill out a worksheet that helps them try to explain what they have observed. Two to three additional scenarios are then presented to provide further practice on applying important dynamics concepts. By participating in IBLAs, students should increase their conceptual understanding and repair their misconceptions of critical dynamics concepts.

At our institution, a common final is implemented for the undergraduate dynamics students at the end of each quarter. During the Winter Quarter 2016, some classes participated in a specific Spool IBLA while other classes did not. The Spool IBLA allowed students to investigate the dynamic behavior of a rolling rigid body. A common demonstration among dynamics instructors, the spool is used to examine the relationship between linear acceleration, force, angular acceleration, moments, and friction. On the common final, a spool question asking the directions of motion and of the friction force was given. Students had to both find the nominal answer to the question as well as write out their justification for their answer. The aim of this report is to compare the responses from students who participated in the Spool IBLA with those students who did not.

Introduction and Background

It has come to our attention that many engineering students complete their dynamics course without deep conceptual understanding of the principles involved. Ongoing research has been completed to further understand this phenomenon and how we as educators can better instill a conceptual understanding of dynamics in our students. We have found that presenting engineering students with a physical situation and having them predict the outcome can create an engaging learning environment. By participating in a hands-on activity and making predictions about the results, students can test their conceptions and let the physical world be the authority rather than just the word of the instructor. Based on the work of Laws et. al.[1] and highlighted by Prince and Vigant[2], these hands-on activities are known as Inquiry-Based Learning Activities (IBLA) and follow the general cycle shown in Figure 1.

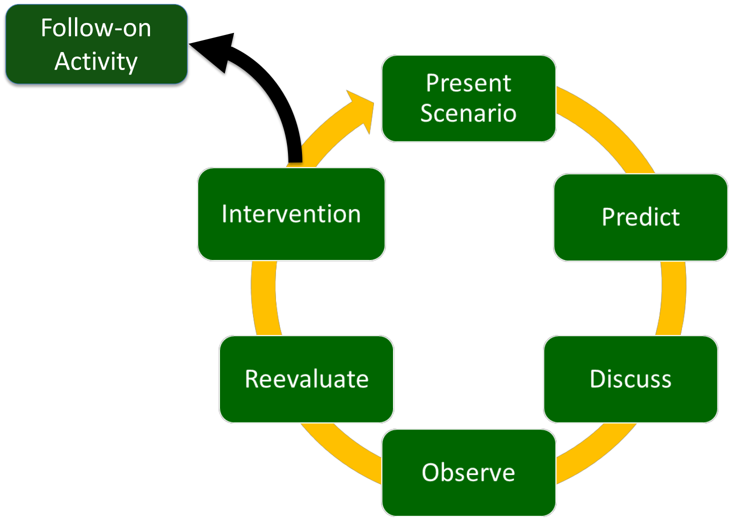


Figure 1. Learning cycle for IBLAs.[3]

While five different IBLAs have been developed at our institution[4], only the Spool IBLA will be discussed throughout this paper. In order to investigate the dynamic behaviors of a rolling rigid body, students were presented with four different spool scenarios and asked three corresponding questions as seen in Figure 2 during the Spool IBLA.

1.Looking at the figure in scenario #X, if you pull on the string gently, which way do you predict the spool will move?

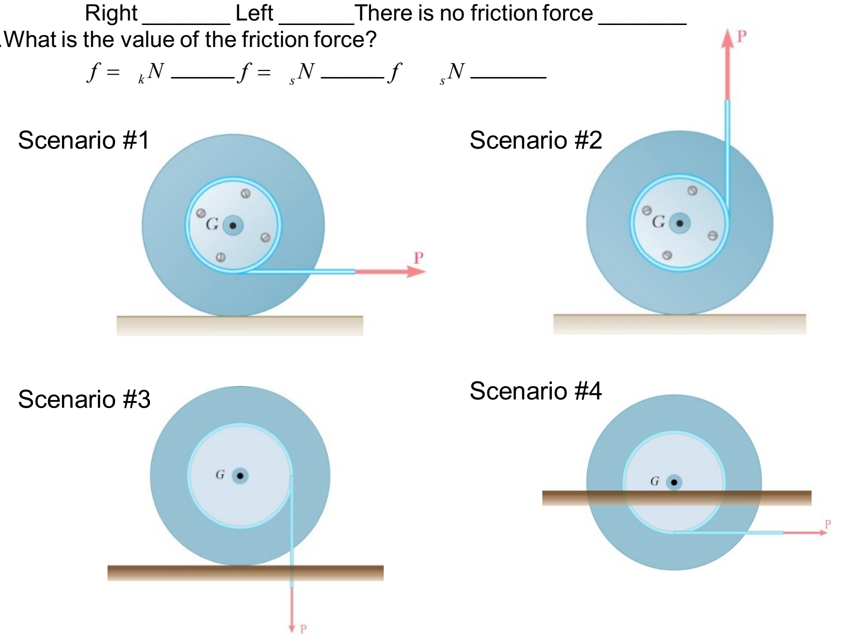
Right ________ Left ______Won't Move________

2.When pulling, which direction is the friction force?

Right ________ Left ______There is no friction force ________

3.What is the value of the friction force?

$f = \ _k N$ ______ $f = \ _s N$ ______ $f \ \ _s N$ ______



.

Figure 2. Spool IBLA (Cases 1-4).[3]

At the beginning of class, students were separated into teams, presented with the first scenario, and asked to make individual predications. Next, they discussed their predictions with their teammates before recreating the scenario with a physical spool as seen in Figure 3. After both Scenario 1 and 2, the professor "intervened" and discussed the logic behind the rolling behavior with the intention of resolving any student confusion. Upon completion of the second intervention, students returned to the activity and repeated the process for the last two scenarios.

Figure 3. Student recreating Scenario 2 from Figure 1.

Spool IBLA Dynamics

The Spool IBLA is intended to provide a physical example to a non-intuitive dynamics problem. The phrase "pull on the string gently" implies that the spool is rolling without slip. Knowing this, the students should be able to apply three basic principles to each of the spool scenarios:

1. The direction of acceleration ($\boldsymbol{a}$) of the mass center is in the same direction as the sum of the forces ($\sum \mathbf{F}=m\mathbf{a}$);
2. The direction of angular acceleration ($\boldsymbol{\alpha}$) is the same as the direction of the sum of the moments about the mass center ($\sum \mathbf{M}_G = I_G * \boldsymbol{\alpha}$)
3. The direction of rolling must be compatible with the direction of translational movement (the directions of $\boldsymbol{\alpha}$ and $\boldsymbol{a}$ must be compatible).

A very common pre-conception of students is that the direction of the friction force must oppose the direction of the translational motion. Although some students can correctly predict the direction of friction by examining the relative displacement of the wheel on the floor, our two interventions attempt to explain the motion of the spool and the direction of friction in the larger context of principles (1) – (3) above.

A problem-solving logic was presented to the students during the professor-led interventions in which an assumption about the direction of the spool or friction force was made and the system was checked to see if it followed principles (1) – (3). For Scenario 1, force $\boldsymbol{P}$ caused a counterclockwise (CCW) moment about G which would tend to angularly accelerate the spool CCW with a linear acceleration to the left. However, the direction of the friction force cannot be determined as easily. Next the free body diagram (FBD) and kinetic diagram (KD) were drawn. In the first option, it was assumed that friction was to the right. While this is consistent with the sum of moments condition in principle (2), the friction force and the linear acceleration of the spool do not equate thus violating principle (1). The slide from the professor-led intervention can be seen in Figure 4.

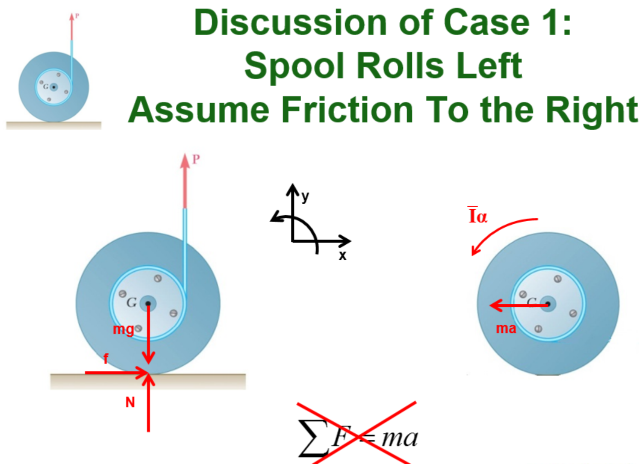


Figure 4. Slide from presentation used during professor-led intervention for scenario one during Spool IBLA with the assumption that friction acts to the right.

Since the first assumption in the problem solving logic was inconsistent with the dynamic principles, the new assumed solution was that the friction acts to the left. The FBD and KD were once again drawn. This time, all three principles were satisfied and the correct solution was determined as seen in Figure 5.

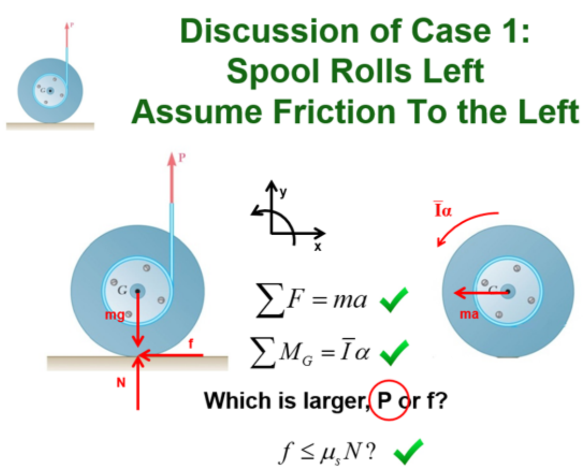


Figure 5. Slide from presentation used during professor-led intervention for scenario one during Spool IBLA with the assumption that friction acts to the left.

In scenario 2, the direction that the spool rolls cannot be determined as easily as Scenario 1. Thus, it was first assumed that the spool would roll to the left (CCW) with the corresponding linear acceleration to the left. To satisfy the summation of linear forces and accelerations, the friction force would need to act to the left and have a larger magnitude than the force ***P***; however, since the friction force acts at a larger radius from G than the force ***P***, it would create an angular acceleration CW which is inconsistent with the KD and violates principle (3) as seen in Figure 6.

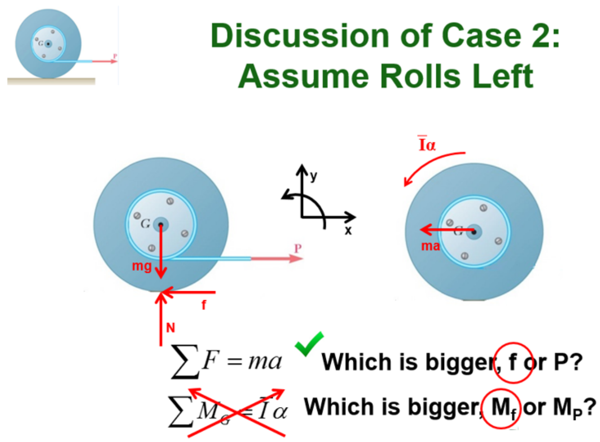


Figure 6. Slide from presentation used during professor-led intervention for scenario two during Spool IBLA with the assumption that the spool rolls left.

This must mean that the spool will roll to the right. In order to satisfy the CW direction of the angular acceleration, the friction force must act to the left since the force ***P*** acts to the right. Additionally, as long as the force ***P*** is larger than the friction force, the linear forces can equal the linear acceleration of the system thus satisfying all principles (1) – (3) as seen in Figure 7. While there were only two interventions shown for the first two scenarios, students were encouraged to use a similar problem solving logic when completing the rest of the IBLA as well as any rolling rigid body kinetics problems they might encounter in the future.

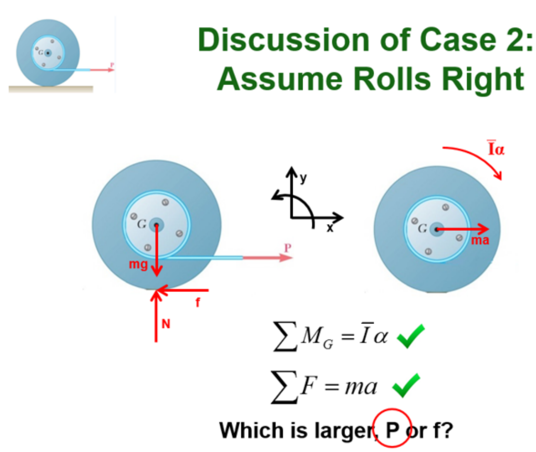


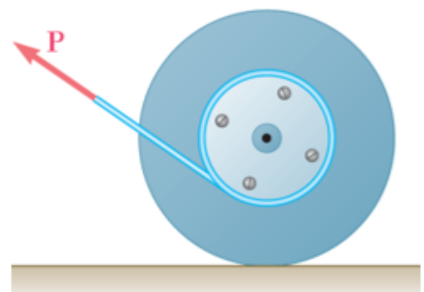
Figure 7. Slide from presentation used during professor-led intervention for scenario two during Spool IBLA with the assumption that the spool rolls right.

Results

Eight of the dynamics sections, each with approximately 35 students, from Winter 2016 were analyzed for this paper. Four of the sections participated in the Spool IBLA while the other four sections learned about the behavior of rolling rigid bodies in a more traditional classroom setting. At our institution, a common final is given to all undergraduate engineering dynamics students. As seen in Figure 8, a conceptual question involving a spool was asked during the Winter 2016 common final. In addition to answering the two multiple choice questions about the movement and friction force, students were also asked to explain their reasoning and were provided space to draw diagrams, complete calculations, etc. The results from the common final for all eight sections were compiled and analyzed. Figure 9 shows the student responses for the multiple choice questions.

(4pts) You pull gently on the spool with a force *T* and cause it to roll without slip. Which way will the spool move?

a. To the left
b. To the right
c. Upwards
d. Not enough information to tell



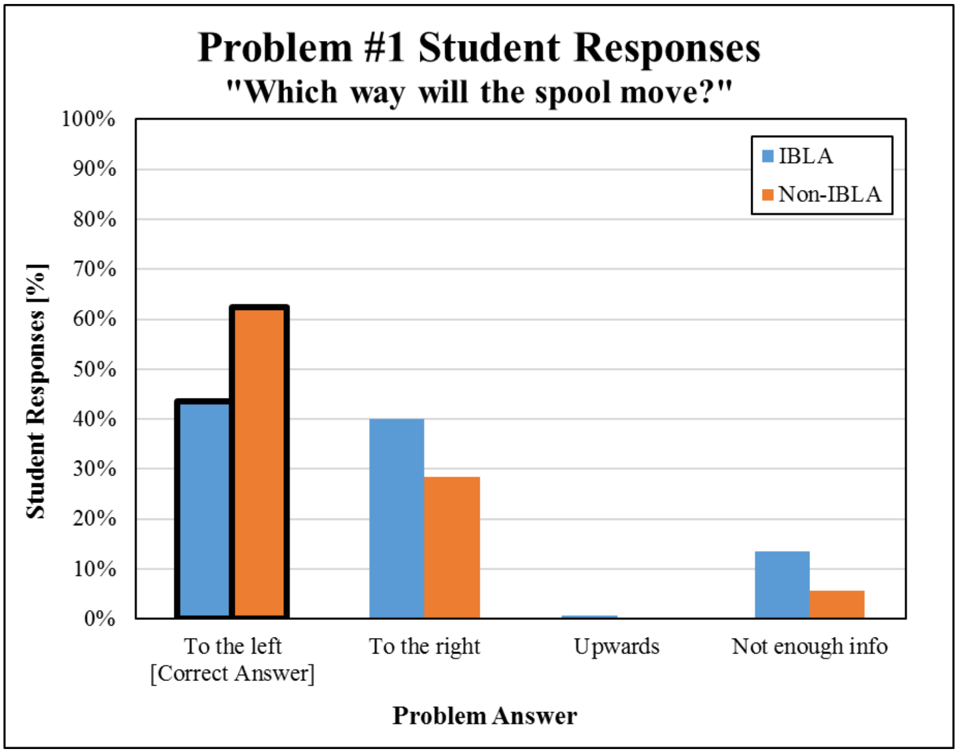
Which direction will the friction force act?

a. To the left
b. To the right
c. Upwards
d. Not enough information to tell

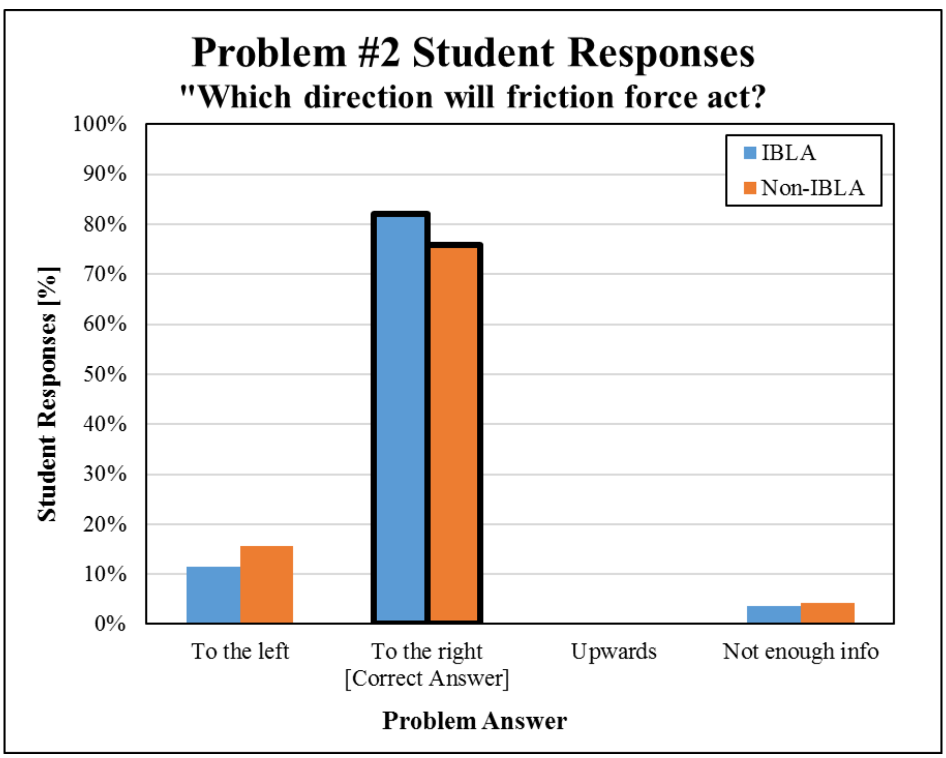
Briefly explain your answer:

____

Figure 8. Spool conceptual question asked on the undergraduate dynamics common final.



(a)



(b)

Figure 9. Student responses to multiple choice conceptual questions seen in Figure 8. The correct answers are labeled in the axis and outlined.

As seen in Figure 9(b), many students were able to successfully determine the direction of the friction force regardless of whether or not they participated in the Spool IBLA; however, there was a discrepancy amongst IBLA and non-IBLA students in determining which way the spool would move as seen in Figure 9(a). Significantly more students who participated in the Spool IBLA incorrectly answered the first question regarding the spool motion as compared to their non-IBLA counterparts.

After the initial multiple choice question analysis, the explanations of the students were sorted by common answers. The IBLA students typically had free body diagrams (FBD), kinetic diagrams (KD), summations of forces ($\sum F$), summation of moments ($\sum M$), and the concept that the tangential acceleration had to agree with the rotational acceleration ($a = r\alpha$). Additionally, approximately 50% of the IBLA students applied a similar problem-solving logic that was used during the Spool IBLA. Some of the IBLA students even mentioned the IBLA in their justification.

Student A's response, as seen in Figure 10, is a good example of an IBLA-like problem solving logic. Student A presented two possible scenarios in which the spool either rolled to the left or to the right. While the forces and moments were not formally summarized, Student A recognized that the linear acceleration and the rotational acceleration needed to complement each other ($a = r\alpha$). In the scenario where the spool moves to the right, while the net force would cause an acceleration to right if the friction force was larger than force ***P***, this would result in a sum of moments that would angularly accelerate CCW which is not possible. Thus, as Student A explained, the only plausible scenario is one in which the spools moves to the left. By having the pulling force larger than the friction force, the spool can still move with a linear acceleration to the left. While the magnitude of the pulling force may be larger, the friction force has a larger radius and can successfully create a CCW moment, thus satisfying the sum of forces and sum of moments equations.

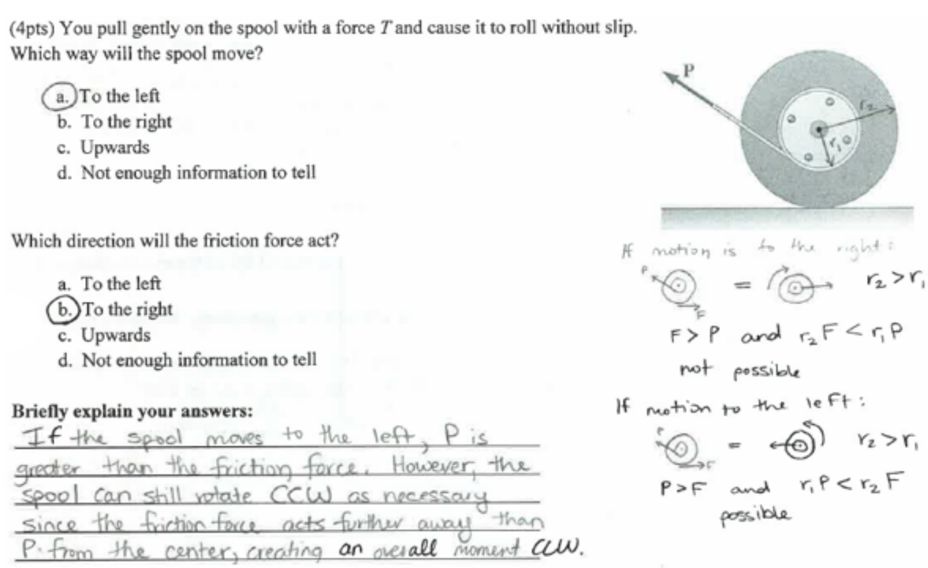
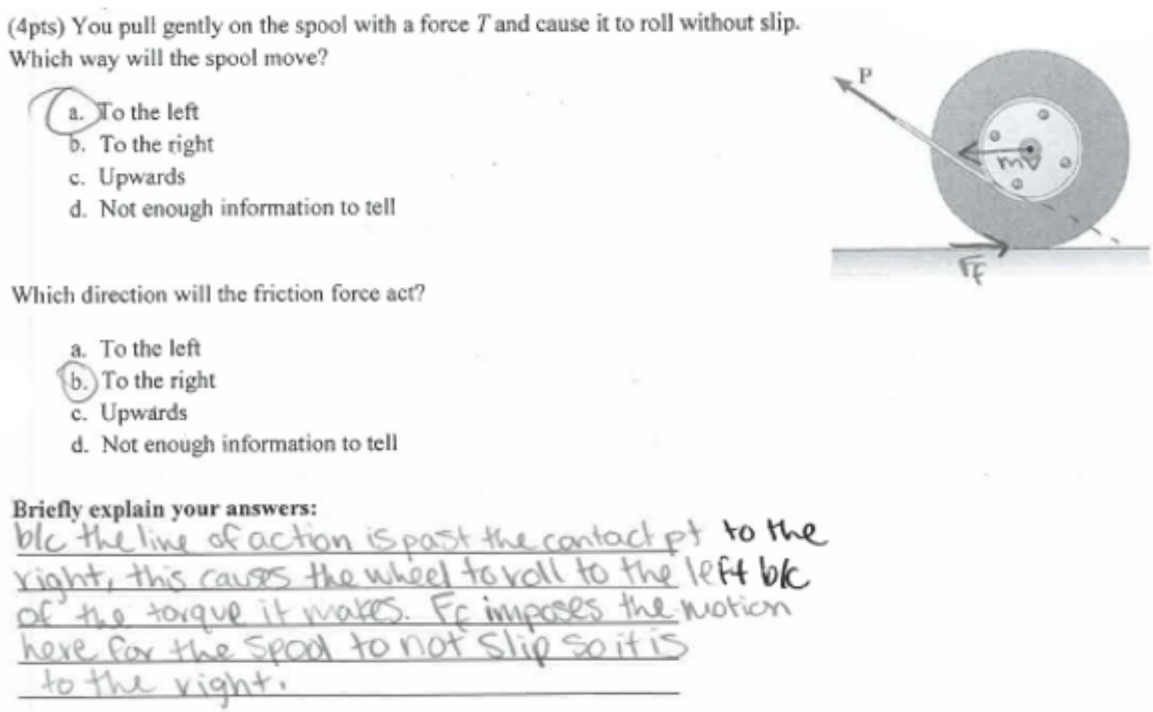


Figure 10. Student A's response utilizing a similar approach as seen in the IBLA. Student A participated in an IBLA.

Many of the IBLA students attempted to justify their answers with a similar approach by analyzing the two scenarios in which the spool moved to the right or to the left; however, as seen in the results in Figure 9, they did not perform as highly as the non-IBLA students. A possible reason for this discrepancy is that all of the spool IBLA scenarios involved horizontal or vertical pulling forces unlike the angled pulling force asked during the common final. It would have been more ideal if the spool question on the final was one of the scenarios completed during the IBLA.

After closer analysis of the non-IBLA student justifications, we discovered that many students utilized a very specific problem solving tool to correctly answer the question. In three of the four sections of students who did not participate in the Spool IBLA, the instructors taught their students to utilize a “line of action” approach when solving a spool problem. This can be seen in Student B’s response in Figure 11.


(4pts) You pull gently on the spool with a force T and cause it to roll without slip. Which way will the spool move?

a. To the left
b. To the right
c. Upwards
d. Not enough information to tell

Which direction will the friction force act?

a. To the left
b. To the right
c. Upwards
d. Not enough information to tell

Briefly explain your answers:
b/c the line of action is past the contact pt to the right, this causes the wheel to roll to the left b/c of the torque it makes. Fc imposes the motion here for the spool to not slip so it is to the right.

Figure 11. Student B’s response utilizing the “line of action” methodology.
Student B did not participate in an IBLA.

Since the contact point C is not accelerating at the base of the spool, students were taught to equate the sum of moments about this point to $I_c * \boldsymbol{\alpha}$. However, many non-IBLA students in general did not apply this technique, but simply memorized the tool where if the line of action of the force $\boldsymbol{P}$ was to the left of C, it rolled CW. While the “line of action” approach resulted in more students correctly answering the first question, it is an approach that is only applicable for this *specific* type of problem.

To understand the method of approach that the students were taking, we coded the students approach based on which solution tool they used. The results can be seen in Figure 12. A significant number of IBLA students attempted to utilize more general dynamics problem-solving tools and concepts as compared to the non-IBLA students. Furthermore, almost 30% of the non-IBLA students solved the problem using the line of action methodology (keeping in mind that only three out of the four sections learned the "line of action" tool in class).

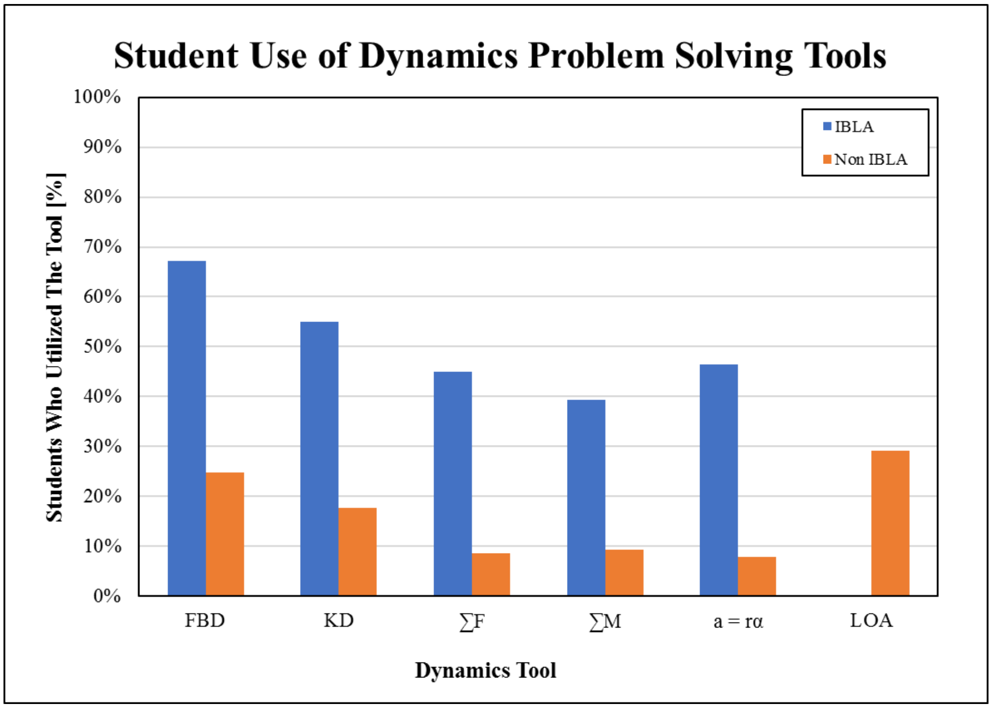
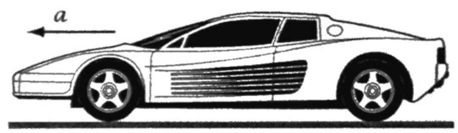


Figure 12. Common methods of approach that students used to solve the spool problem.

These results led us to believe that, while the IBLA students may have underperformed on this specific question, they were *better prepared* to answer the question. One of the main goals of the Spool IBLA is to provide students with a methodology for solving all kinetics problems, not just rolling rigid body problems involving a spool. To verify this hypothesis, the results from the Dynamics Concept Inventory (DCI) were analyzed. The DCI is a survey given to our engineering undergraduate students before and after they complete their dynamics course that allows educators to analyze the overall conceptual understanding of students. One of the questions on the DCI analyzed the rolling body dynamics on the rear wheel of car. This transfer question can be seen in Figure 13.

Question 27



For the *rear* wheel drive car, consider a situation in which the car starts from rest and accelerates to the left. The tires do not slip on the road. Assume the normal force on the rear tires is N_{rear} and the coefficients of static and kinetic friction are μ_s and μ_k, respectively. The friction force, F_{rear}, on the *rear* tires is given by what expression and what is its direction?

(a) $F_{rear} = \mu_k N_{rear}$ to the right.

(b) $F_{rear} = \mu_k N_{rear}$ to the left.

(c) $F_{rear} \leq \mu_s N_{rear}$ to the right.

(d) $F_{rear} \leq \mu_s N_{rear}$ to the left.

(e) Not enough information is given.

Figure 13. DCI Rolling rigid body conceptual question.

Like the different IBLA spool scenarios, Question 27 required that students utilize principles (1) – (3) that were mentioned earlier in the report; however, since it was not specifically a spool problem, the students could not utilize the "line of action" approach. As seen in Figure 14, IBLA students outperformed the non-IBLA students by approximately 20%, thus supporting the hypothesis that the IBLA may have provided students with more applicable experience and the appropriate dynamics tools to more general rolling rigid body problems.

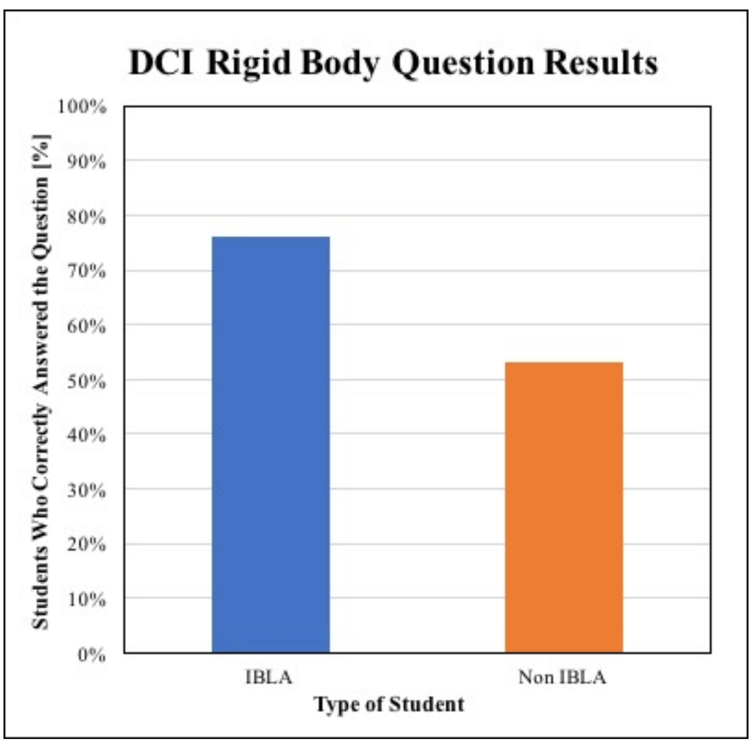


Figure 14. DCI Rolling rigid body question results.

Conclusion

The goal of our IBLA's are to provide undergraduate engineering students with hands-on activities that reinforce their conceptual understanding of dynamics principles. To compare the usefulness of the Spool IBLA, specific results from the rolling rigid body problems from both the common final and DCI were analyzed. While IBLA students underperformed during the spool-specific problem in the common final, it became apparent that a unique "line of action" approach was utilized by many of the non-IBLA students to achieve the correct answer. However, as seen by the results of the DCI, when students had to rely on basic dynamics tools to solve a more general rigid rolling body problem, it appears that the students who participated in IBLA had a better conceptual understanding of what was occurring. While it may be helpful to implement the "line of action" technique when teaching students about spools specifically, IBLA's are still an extremely powerful tool that can help provide students with a real-world reinforcement of their dynamics concepts.

Acknowledgements

Support for this work was generously provided by the National Science Foundation, NSF #1044282, "Using Inquiry-Based Activities to Repair Student Misconceptions in Engineering Dynamics." Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

References

1. Laws, P., D. Sokoloff, and R. Thornton, *Promoting active learning using the results of physics education research.* UniServe Science News 1999. 13.
2. Prince, M. and M. Vigeant, *Using Inquiry-Based Activities to Promote Understanding of Critical Engineering Concepts*, in *ASEE Annual Conference & Exposition*. 2006.
3. Self, B. *Increasing Conceptual Understanding and Student Motivation in Undergraduate Dynamics Inquiry-Based Learning Activities*. Tech. ASEE, 2016.
4. Self, B.P., J. Widmann, M. Prince, and J. Georgette. *Inquiry-based learning activities in dynamics*. in *Proceedings of the American Society for Engineering Education Annual Conference and Exposition.* 2013.