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Work In Progress: Implementation of a Dynamics Concept Inventory – Before and After a Dynamics Class

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Implementation of a Dynamics Concept Inventory – Before and After a Dynamics class

Abstract

Concept inventories are prevalent in Physics and Statics classes but not many have been developed for Dynamics. Expanding on the success of Force Concept inventories used in Physics, one Dynamics Concept Inventory (DCI) has been identified and was used in a traditional planar rigid body Dynamics class. The DCI test contains questions regarding different dynamics concepts using a 29-question multiple choice test. The DCI was implemented before and after a Dynamics course at a four-year, medium size, primarily residential public institution. The objective is to begin to identify concepts which students have trouble with and how progressing through a dynamics course may affect the student's understanding of those concepts.

This paper contains the results and analysis from two classes' responses to the DCI test. Initial results of the exam indicate students do not have a good "feel" for dynamics before entering the course. The average score on the exam was a 26% and 22% in each year respectively. Interestingly consistent between the two classes are the inability to correctly identify the instantaneous velocity profile of a rotating object (<5% of students answered correctly), and a location of the minimum velocity of a tire driving a vehicle's motion – the no slip condition (<5% of students answered correctly). In addition, consistent between the two classes are a strength in particle motion questions (>60% of the students answered correctly) and rigid body energy questions (>60% of the students answered correctly). Comparing results from the pre- and post-course tests, there was not much improvement in these areas of low comprehension – which is what we would hope for after implementing a course on the topic. In fact – there are large decreases in areas of at which students initially showed strength in the pre-course DCI test. In the following paper we will discuss the results of the full set of data (pre- and post-course DCI exams from two different semesters). As we move forward, we will be interested to include results from a large public institution for comparison and determine adjustments that may be necessary to help improve conceptual understanding of Dynamics.

1 Introduction

Mechanics courses are the foundation of many engineering programs. In an effort to improve teaching and learning, concept inventories are a mechanism that have been used to evaluate both teaching and learning [1]. Concept inventories are prevalent in Physics, as Force Concept Inventories (FCI), [1]–[4] and in Statics [5]–[8]. Not many concept inventories have been created to focus on the topic of Dynamics. Expanding on the success of the FCI, Gray et al. [9] have created and are fine tuning a Dynamics Concept Inventory (DCI) test. The test examines 11 different concepts over a 29-question multiple choice exam and since its inception, has been analyzed to have “adequate” reliability [10]. In addition, there has also been some work to investigate a shortened version of the same DCI [11].

In this study, the DCI was implemented at the very beginning (pre-course) of two Fall Dynamic courses (in 2018 and 2019) at a public university and then again at the very end of the same course (post-course). The objective here is to assess student understanding of dynamics concepts before and after a dynamics course. Overall, we will identify concepts that students retain, improve understanding of and lose understanding of through a Dynamics course. Specifically, identifying potential misunderstandings that persist after a traditional lecture-style approach will allow for development of targeted demonstrations to address these potential misunderstandings.

2 Methods

A Dynamics Concept Inventory was administered on the very first day of an introductory Dynamics class. Instructions for the test is to administer it with a time limit of 30 minutes. After the test, the introductory dynamics course followed. The course consisted of 2 lectures per week for 1 hours and 15 minutes per day for 15 weeks. There were 2 semester exams and 1 final exam.

Daily lectures were made up of a brief introduction to the topic and followed with general problem-solving techniques with occasional intuitive questions as to problem set up and validity of solution. Students are provided a handout with 3 problems and answers, but no solution. A typical lecture is divided into 3 sections. The first section included an instructor led problem set-up and derivation of equations with general explanation of assumptions and theory. The second part of the lecture left students to work with each other to develop diagrams and equations. After completing their solution, students are requested to share parts of their solution (written by the instructor on the front board) to develop the correct solution. During this section of the class, students are questioned regarding their intuition as to how equations and diagrams are developed. The final part of the lecture is student led where the development of diagrams and equations are led by questioning of students (by the faculty). Concepts are discussed throughout the lecture/class in the context of the equations implemented in solving the problems. Finally, at the end of the semester, during the last class, students are asked to take the DCI test again. The same time limit of 30 minutes is enforced.

For each offering of the DCI, the average score, lowest performing questions, and highest performing questions were identified. Results were qualitatively and quantitatively compared between the beginning and end of semester offerings of the DCI. Specifically, a Fisher's exact test of independence was conducted to examine if the proportion of students with the correct answer changed from beginning to the end of the semester ($p < 0.05$).

3 Results

Below we present summaries of the DCI test results for when students took the exam before and after delivery of a Dynamics class. We include a comparison of performance from pre- and post-course tests. We will investigate topics students answer consistently correct or consistently incorrect. Finally, we include a few results comparing scores on exam problems compared with those on the DCI test.

3.1 Before Administration of a Dynamics Course

The average score on the DCI test pre-course is 26.4% for all students. The lowest performer had scored 10.3% (3 correct answers) and the high performer scored 51.7% (15 correct answers). Students performed the best on questions about particle kinematics and particle collision – with over a 60% of the students providing a correct response (Table 1). In addition, students performed well on a question regarding quantifying energy of rigid bodies in rotation. Students did not perform well (only ~4% of students tested having the correct response) on questions regarding velocity and acceleration of points on rigid bodies and the effect of inertia or force on acceleration of particles. This is expected as these are topics that are not introduced in pre-requisite course work (i.e. Introductory Physics or Calculus courses).

Table 1: Results of Pre-Course Dynamics Concept Inventory

Pre-Course (n=56)		
	Topic	**Percent correct**
High	Particle motion	64.3%
	Rigid Body Energy (rotating vs. translating bodies)	60.7%
	Impacts	55.8%
Low	Five part accel Vector (Coriolis)	5.3%
	Velocity Vectors on a Disk	3.6%
	Linear velocity vectors on a disk	1.8%

3.2 Post-Course Results

The average on the DCI test after the course was a 26.9% for all students. The lowest performer scored 6.9% (2 correct answers) and the high performer had 48.3% (14 correct answers). Concepts with the highest performance included particle motion, rigid body energy and impacts concepts (Table 2). Concepts with the lowest performance included identification of velocity vectors on a disk, the effect of inertia or force on acceleration of particles, the no-slip condition, and friction (slipping) (Table 2).

Table 2: Results of Post-Course Dynamics Concept Inventory

Post-Course (n=50)		
	Topic	**Percent correct**
High	Particle Motion	62.0%
	Disk Inertia	50.0%
	Impacts	48.0%
Low	Linear velocity vectors on a disk	2.0%
	Pulleys (Inertia vs. Force)	4.0%
	No Slip Condition	8.0%
	Friction (Slipping)	8.0%

However, still one of the more difficult concepts to grasp are the profiles of velocities of rotating rigid bodies, differences between inertia and forces acting on ropes and pulleys, and friction.

3.3 Pre- and Post-Course Comparison

The overall DCI average increased by only 0.5% with the extreme values shifting to lower scores (10.3% to 6.9% minimum score; 51.7% to 48.3% maximum score). Throughout the course, students did improve the most on their understanding of the direction of friction applied to driven wheels on cars (21.75% change from pre-course to post-course; Table 3). However, at the same time, student's correct response decreased on a similar question referring to determining the direction of the friction force on NON-driven wheels (slip vs. no slip) - decreasing 18.9% from pre-course to post-course. Other topics on which there was a large decrease from the start of the semester to the end of the semester included comparing energies of rigid bodies in motion, the same question in which students performed the BEST at the start of the semester, and rigid body angular momentum. Interestingly, we found the proportion of students answering correctly on the rigid body energy problem significantly decreased from beginning to end of the semester (p=0.007). We observed similar results for Rocket Thrust (speed) question (p=0.048). We also found the proportion of students correct significantly increased from beginning to end of the semester for rigid body friction (p=0.015).

Table 3: Largest changes in Post- to Pre-course DCI response

3 Largest Differences		
	Topic	**Percent change**
Positive Difference	Angular velocity vectors on a disk	9.70 %
	Impacts	13.73 %
	Rigid Body - Friction #27	18.9 %
Negative Difference	Rigid Body Energy (rotating vs. translating bodies)	-26.7 %
	Rocket Thrust (Speed)	-20.0 %
	Rigid Body - Friction #28	-16.19%

3.4 Consistency Among Students

We also investigated the topics in which students consistently answered correctly and incorrectly from the pre-course to the post-course DCI test. So, for example (See Table 4, below), if a student answered correctly on a question related to using the Five Part Acceleration Vector (Coriolis) on the pre-course DCI test, all of those students (100%) answered the question correctly on the post-course DCI test. And on the same question, if a student answered the Five Part Acceleration Vector (Coriolis) incorrectly on the pre-course DCI test, 91% of those students answered the problem incorrectly on the post-course DCI test. Sadly, this means that only 9 % of those students who had a misconception on this topic improved their conceptual understanding.

Now, of course, this does not mean necessarily that a student did not learn the concept and, given a problem, couldn't work through it. It simply means that their intuition has not been trained well enough to visualize the correct result.

Table 4: Consistency

	Topic	Percent # of Students
Consistent Correct	Five Part Accel Vector (Coriolis)	100%
	Rigid Body Friction	75.00%
	RB Velocity Profile	69.23%
Consistent Wrong	Linear velocity vectors on a disk	97.92%
	Pulleys (inertia vs force)	97.73%
	Five Part Accel Vector (Coriolis)	91.49%

3.5 In Course Comparison

When comparing the answers of these questions to student performance on course exam problems, there were only three exam problems that could be easily be directly compared to the DCI questions (Table 5). Other questions on the exams may have included components of concepts tested on the DCI test, but included multiple parts that made it difficult tease out a fair comparison. On these exam questions, students had mixed performances. When comparing a particle impact problem from an exam to their response on the DCI, students performed just as predicted by the DCI. However, exams illustrate that students are capable of doing the work necessary to calculate components of problems incorporating friction and/or velocities and accelerations but have yet to develop the intuition associated with the concepts. It is possible that students are memorizing problems to develop a problem 'bank', matching a test question to one in the problem 'bank' as closely as possible, and using the memorized solution with minor adjustments to maximize partial credit [12], and therefore not demonstrating conceptual knowledge gains.

Table 5: In Class Comparison

Comparison				
Topic	**DCI Pre-Course**	**DCI Post-Course**	**Exam Problem Score 2018**	**Exam Problem Score 2019**
Particle Impacts	55.4%	53.3%	61.80%	
Friction (#27)	27.0%	18.8%	--	73.50%
Five Part Accel Vector (Coriolis)	5.3%	13.2%	55.80%	

Finally, it is worth noting here that there was one student whose results were thrown out due to not filling our more than half of the DCI test. In addition, there were 11 students (of the original 56) that did not participate in the end-of-semester DCI test. Three of these 11 students had the high scores (10-13 correct out of 29 questions) at the very beginning of the semester. Students who did not complete the end-of-semester DCI test were not included in comparisons between beginning and end of semester scores.

4 Discussion

The results suggest that students retained their conceptual knowledge on particle kinematics and particle collision and had some improvement in their knowledge of kinematics and effect of inertia on rotating bodies. It is encouraging to see that students do not lose their knowledge of particle motion after going through a dynamics course. In addition, progressing through the course did have a positive effect on their performance on questions regarding angular velocity vectors on rigid bodies. This makes sense and is encouraging, because this is probably a new topic for the students based on the curriculum design. There was a positive effect on a student's understanding of friction forces on driven wheels. The improvement on this topic is not unexpected because the topic is discussed near the end of the course, and therefore near the post-course DCI test. In addition, this is a topic that is often confusing for students, therefore an in-class demonstration of a small rotating tire is used in lecture to emphasize directions of forces on driven wheels. This, however, seemed to have been negated by a large drop in understanding of forces acting on non-driven wheels. Finally, it seems as if student's sense of energy of rigid bodies is drastically changed, for the worse. However, these topics are not explicitly covered in the course, or if they are, it is very cursory and as the very last topic of the semester.

One of the ways to improve a student's intuition on these sorts of questions may be to ask the students to first write a formula associated with each concept, or identify the properly drawn free body diagram, and then ask them to answer the conceptual question. After going through a dynamic course that is based heavily on drawing diagrams and problem solving, it would be interesting to first ask students to identify the correct figure or equation associated with the problem and then ask them the conceptual question. After having progressed through a Dynamics course in which they are consistently solving problems, a student may fair better in illustrating their conceptual understanding of material by first identifying the proper equation and then answering the conceptual question or by formally posing more conceptual questions in class or on exams.

5 Conclusion

It's not unexpected that students did not perform better on the DCI test after the course. Dynamics courses are not always taught with the idea of addressing these types of questions conceptually. Because exams and homework are focused on problem solving, much of the lecture is focused on how to set up and solve dynamics problems. That is not to say that NO conceptual questions are addressed in the lecture or in the homework, but it is NOT the focus of these tasks. Therefore, students are not practiced in answering these types of questions in a limited time frame; so, it is not unexpected that they did not perform well.

Concept inventories are a powerful tool in the educational toolbox. They can be used to establish a baseline for the course and/or student. Results indicate how well students understand concepts and (if applied before and after a course) retain and/or gain information through the course. Although it probably should not be an absolute measuring stick, because students are probably capable of problem solving without fully predicting a response to illustrate knowledge of a concept.

Concept inventories are also informative to the instructor. Results indicate topics that may be weak in student knowledge and the faculty's ability to convey. If, as educators, we are working towards continuous improvement of our lectures and/or delivery, Concept inventories are an excellent tool to help us along our way. They can be used as a method of illustrating to students when and where their intuition may fool them, when their knowledge of the material will help them to work through problems, and when they should rely on calculations to help adjust their intuition. This exercise has certainly provided a moment of self-reflection for the authors and a direction towards improvement of their courses.

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