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A Modified Concept Inventory for Dynamics

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Work in Progress: A Rigid Body Dynamics Concept Inventory

Introduction

The Dynamics Concept Inventory (DCI) has been around for over 20 years [1], [2], [3], [4]. Since its release, it has been both downloaded over 150 times and used by faculty through the Concept Warehouse website [1]. The DCI started out as a paper-only version using a locked PDF and an answer key that had to be requested from the authors. In the 20 years since, the DCI has been added to the Concept Warehouse where faculty can deploy it and get student response data for use in their classes. The Concept Warehouse was originally developed for use in the Chemical Engineering community to better provide students with concept-based instruction [5]. It has been expanded to contain hundreds of concept questions including topics in Dynamics as well as other courses in Mechanical Engineering [6]. Additionally, others have used a shortened version of the DCI as a method for testing instructional methods with the goal of minimizing instructional differences across sections [7].

This paper discusses the beginnings of an effort to build a concept inventory with a focus on *rigid body dynamics*. The concepts associated with particle kinetics and particle kinematics topics are covered in other concept inventories [8], so those ideas will not be included in this new concept inventory to prevent redundancy. A new concept inventory will provide an instrument for faculty to assess some of the more difficult concepts in dynamics as students tend to come into a dynamics course and do well on particle dynamics questions because of their background in physics. In a study to explore student perceptions of difficult concepts in dynamics, Fang found that students overwhelmingly ranked fundamental concepts dealing with *rigid bodies* as the most difficult [9]. The new Rigid Body Dynamics Concept Inventory will contain 10 concepts focused on rigid body dynamics with several corresponding questions developed to isolate those concepts. To do so, previous work and methods on concept inventories [2], [3] are used as a starting point to identify unique concepts.

Throughout the development of the new Rigid Body Dynamics Concept Inventory (RBDCI) - the identification of the concepts and the creation of the questions - the developers will gather feedback from faculty and use student testing to ensure the concepts and questions are valuable and test important rigid body ideas. The feedback and testing will include a confidence and difficulty ranking with each question. The confidence ranking will ask the students to identify their confidence level (i.e., very confident to not confident) in their answer. This ranking, along with the faculty feedback, will provide additional information that can be used to assess difficulty and refine the problems. With this data we will also conduct a Discrimination vs. Difficulty analysis to determine question effectiveness [7].

Progress

Five faculty from across the country have gathered to discuss the creation of this new RBDCI. Each faculty member individually identified topics that should be included in a RBDCI. During bi-weekly meetings the faculty identified a total of 25 topics, which were combined or prioritized to reduce the number to 11 key concepts. The 11 concepts will be used for the question creation phase, where 3-5 questions will be created for each concept. Once the questions are created, they will be tested in various classrooms. Based on the results from evaluating these questions, we plan to reduce the final number of concepts to 10, with three questions for each topic for a total of 30 concept questions for the RBDCI.

The conversations to identify these 11 topics included distinguishing between a rigid body dynamics concept versus focusing on problem solving skills. Problem solving skills are the methods students learn to solve problems in class, which may be unique to each instructor. However, concepts are not unique to the instructor; they are related to a fundamental understanding of how a system behaves. For example, identifying when to use relative velocities and accelerations in rigid body kinematics problems is not a specific key concept to Dynamics. However, it often shows up on linkage problems and is useful to know how and when to use to solve for kinematics of connected links. Conceptual understanding and problem-solving skills are *both* important for students to master, but a concept inventory should identify and test the unique *concepts* to determine a student's understanding of that part of their Dynamics knowledge.

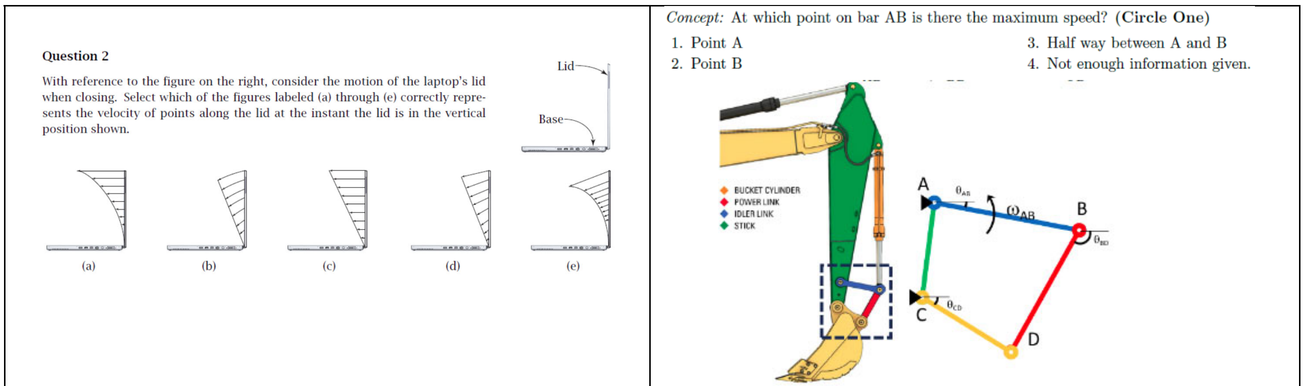
The five instructors each proposed a set of concepts and discussed the overlap and differences due to individual wording. Several proposed concepts were similar to rigid body dynamics concepts identified during the Delphi process used for development of the original DCI [3]. The Delphi process was developed in the 1950s by the Rand Corporation as a means to obtain a reliable consensus among a group of experts. For the DCI the Delphi process was applied through a series of questionnaires given to the experts, along with periodic feedback as discussed in [3]. The similarities in the drafted concepts with the previous Delphi process and amongst the five instructors allowed the similar concepts to be grouped together and ranked, which resulted in 11 final concepts to move forward. Once the concepts were ranked, the final title for each concept was created. The final title tried to reduce the number of words for the concept while still including all the keywords of each instructor's proposal. The final 11 concepts are listed in Table 1.

Table 1: Draft Concepts wording used to identify specific concepts

1	Different points on a rigid body have different velocities and accelerations.
2	The inertia of a body affects its acceleration and velocity.
3	The forces and acceleration of a rigid body are dependent on one another.
4	A rigid body can have both translational and rotational kinetic energy.
5	In general, the total mechanical energy is not conserved during an impact.
6	Coriolis acceleration occurs in rotating reference frames.
7	The angular momentum of a rigid body depends on the reference point.
8	If the net external force F on a rigid body is not zero, then there is an acceleration of the center of mass of that body.
9	Angular velocities and angular accelerations are properties of the rigid body.
10	Points on an object that is rolling have velocities and accelerations that depend on this constraint
11	The action of friction does not always oppose the velocity of the center of a rolling object.

With the final concept titles in place, each instructor began proposing sample questions for each concept. These questions are still being discussed in bi-weekly meetings to reduce and finalize the problem statements and answers. During this phase it is important to determine if a question tests each concept uniquely or if more than one concept is tested. If a question addresses more than one concept, then the question must be rephrased to focus on a single concept. Currently, each concept has a large bank of problems identified by the instructors, and each one is discussed for validity, difficulty, and clarity to determine if it should be kept for the testing phase. The testing phase will involve 3-5 questions per concept that will be beta tested by students and instructors. Through beta testing the questions will be reduced and refined to create the final set of RBDCI concept questions.

The question creation process is currently ongoing, but some examples of proposed questions for three of the concepts are shown in the figures below. *Note*: these are not finalized problems, simply examples of problems that have been used in the discussions. Figure 1 shows two questions that could be used to test Concept 1: "Different points on a rigid body have different velocities and accelerations." Figure 1A is in the current DCI. Figure 1B was proposed for the new RBDCI but has since been eliminated because of the complexity of the figure.



A) In Current DCI

B) Proposed for RBDCI (Eliminated For Complexity) Image edited from [10]

Figure 1: Proposed questions for concept 1 – "Different points on a rigid body have different velocities and accelerations."

Figure 2 contains four questions, two of which come from the current DCI (2B and 2D) and two which come from the Concept Warehouse (2A and 2C) for testing Concept 2: "The inertia of a body affects its acceleration and velocity". Again, these questions are not finalized and are likely not to be used in the final RBDCI in their current state, but these are examples of the types of questions for this concept that have been used for discussion during the question creation phase. The questions in Figures 2A-C test the concept of inertia's effect on kinematics by comparing the motion of a ring versus a disk. These questions are well established and often physically constructed for in-class demonstrations. However, a unique way of testing the same concept is shown in Figure 2D using the effect of rotational inertia on the motion of a pulley.

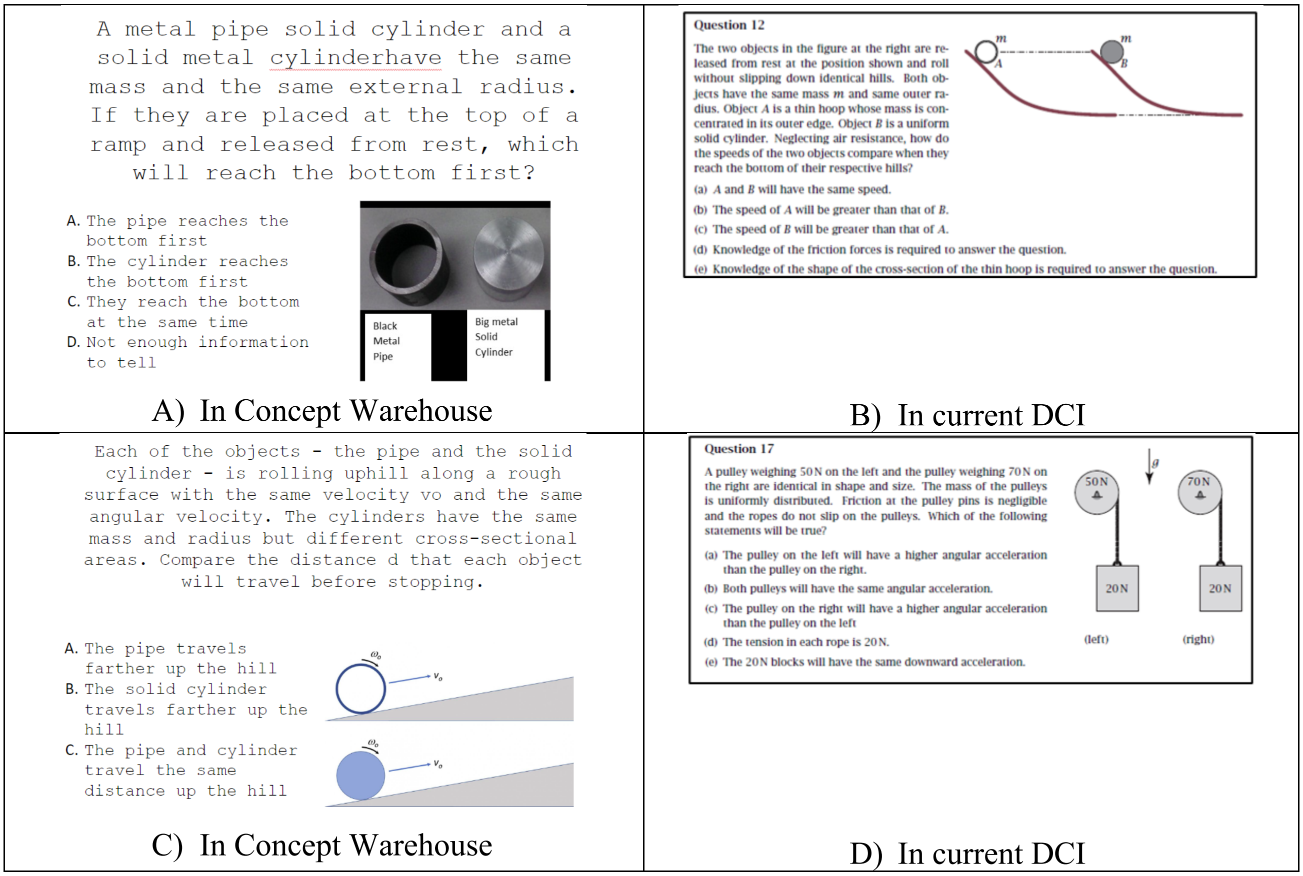
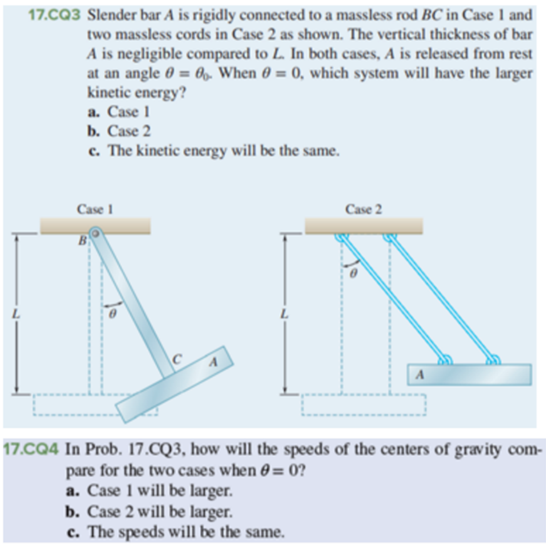


Figure 2: Proposed questions for concept 2 – "The inertia of a body affects its acceleration and velocity"

Figure 3 contains three potential questions for testing Concept 4: "A rigid body can have both translational and rotational kinetic energy". One question is in the current DCI (3B), while the other two test the same concept in different contexts.



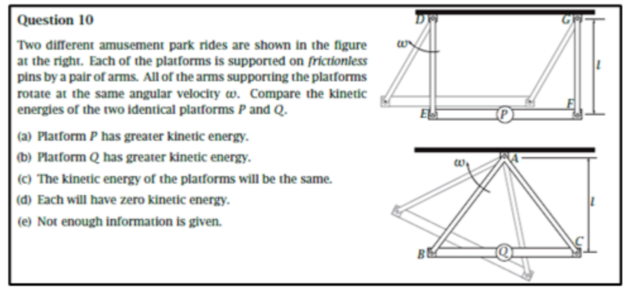
17.CQ3 Slender bar A is rigidly connected to a massless rod BC in Case 1 and two massless cords in Case 2 as shown. The vertical thickness of bar A is negligible compared to L. In both cases, A is released from rest at an angle $\theta = \theta_0$. When $\theta = 0$, which system will have the larger kinetic energy?

a. Case 1
b. Case 2
c. The kinetic energy will be the same.

17.CQ4 In Prob. 17.CQ3, how will the speeds of the centers of gravity compare for the two cases when $\theta = 0$?

a. Case 1 will be larger.
b. Case 2 will be larger.
c. The speeds will be the same.

A) Proposed for RBDCI
Image selected from [11]

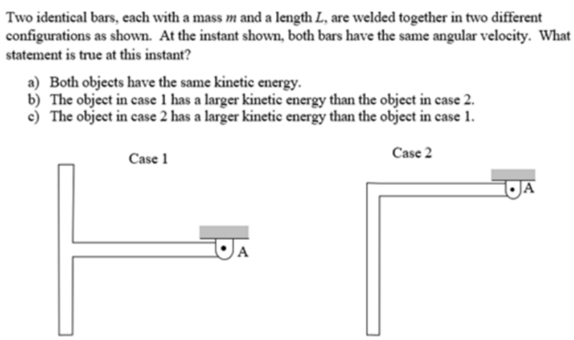


Question 10

Two different amusement park rides are shown in the figure at the right. Each of the platforms is supported on *frictionless* pins by a pair of arms. All of the arms supporting the platforms rotate at the same angular velocity ω. Compare the kinetic energies of the two identical platforms P and Q.

(a) Platform P has greater kinetic energy.
(b) Platform Q has greater kinetic energy.
(c) The kinetic energy of the platforms will be the same.
(d) Each will have zero kinetic energy.
(e) Not enough information is given.

B) In current DCI



Two identical bars, each with a mass m and a length L, are welded together in two different configurations as shown. At the instant shown, both bars have the same angular velocity. What statement is true at this instant?

a) Both objects have the same kinetic energy.
b) The object in case 1 has a larger kinetic energy than the object in case 2.
c) The object in case 2 has a larger kinetic energy than the object in case 1.

C) Proposed for RBDCI

Figure 3: Proposed questions for concept 4 – "A rigid body can have both translational and rotational kinetic energy."

Figures 1-3 contain draft examples of images and problem statements that are being developed for the RBDCI. The final goal for the RBDCI is to have three unique problems testing 10 concepts for a total of 30 questions. Three questions per concept will provide variety in how the concept is posed while allowing the instructor to validate the concept and the individual questions. It will also be important to the individual instructor when interpreting student results as to whether a particular student understands a concept because there will be multiple results for each concept [12].

Figure 4 shows a hierarchical map for the rigid body section of a typical dynamics course. A hierarchical map is a useful tool to help organize and describe relationships between different concepts. In Figure 4, topics are shown in white boxes and concepts associated with each topic are shown in green boxes. We plan to use a map like this to help identify any overlap between concepts and to make sure key topics have concept questions associated with them.

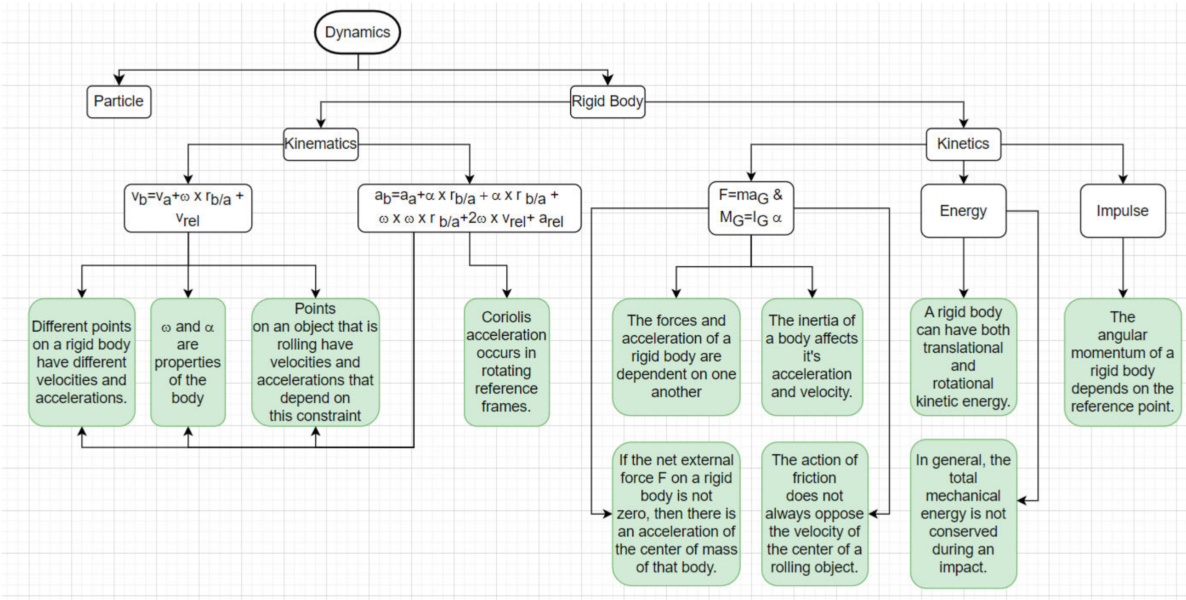


Figure 4: Preliminary Hierarchical Map
Green fills indicate concepts outlined in top 11 concepts agreed as most important.

Future Work

Having distinguished between problem solving skills and concepts to identify the 11 key rigid body dynamics concepts, the team is working to fully develop the questions necessary to test these concepts. Once draft questions are created, they will be sent out for feedback from faculty and beta tested with students to determine if they accurately test the concepts that they are intended to evaluate. Community feedback from faculty will be gathered for both the 11 concepts and the questions. The initial community feedback opportunity will be during the ASEE Annual Conference. The second form of faculty feedback will be obtained through a survey sent out once the questions are finalized. Through the feedback and testing process we will assess the overall instrument for reliability and validity. We plan on using student "Think Alouds" to provide insight into a student's thought process when answering the concept inventory questions. This information should help us improve the distractors and the wording of the problems. Student interviews or focus groups may also be used to provide additional information we can use to improve the validity of the instrument. A reliability analysis will be conducted on beta versions of the inventory. The final form of the RBDCI will have 30 questions that cover 10 unique concepts.

Conclusions

The beginnings of a *rigid body* dynamics concept inventory is taking shape. Five faculty have gathered to identify and rank important rigid body dynamics concepts resulting in 11 concepts to use in initial testing, with the goal of reducing these to 10 final concepts. The questions are currently being developed for the new RBDCI are being evaluated with these questions in mind:

1) Does it examine a Rigid Body concept?

2) Does it match one of the identified key concepts?
3) Does it test only ONE concept?
4) Are there at least three questions per concept?

Affirmative answers to these evaluation criteria will result in a collection of possible questions that can be further tested, evaluated, and refined eventually leading to a new instrument: the Rigid Body Dynamics Concept Inventory.

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