Rigid Body Dynamics: Student Misconceptions and Their Diagnosis[1]

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Introduction: As pointed out by a rich body of research literature, including the three video case studies, *Lessons from Thin Air, Private Universe*, and, particularly, *Can We Believe Our Eyes?*, students subjected to traditional instruction in math, science and engineering often do not adequately resolve the misconceptions that they either bring to a subject or develop while studying a subject. These misconceptions, sometimes referred to as alternative views or student views of basic concepts because they make sense to the student, block the establishment of connections between basic concepts, connections which are necessary for understanding the macroconceptions that build on the basics. That is, the misconceptions of basic phenomena hinder the learning of further material that relies on understanding these concepts.

The literature on misconceptions includes the field of *particle mechanics*, but does not include rigid body mechanics. For example, it has been established[7] "that … commonsense beliefs about motion and force are incompatible with Newtonian concepts in most respects…" It is also known that replacing these "commonsense beliefs" with concepts aligned with modern thinking on science is extremely difficult to accomplish[8]. But a proper approach to accomplishing this replacement must begin with understanding what the misconceptions are, progress to being able to diagnose them, and eventually, reach the point whereby instructional approaches are developed for addressing them.

In high school, college and university physics, research has led to the development of an assessment instrument called the Force Concept Inventory[9] (FCI) that is now available for measuring the success of instruction in breaking these student misconceptions. This work, and the data collected and published on its use[8], have created a very active physics education research community that is pursuing reform in teaching pedagogies and classroom management techniques in that subject.

The Current Work: This paper presents results of research on important, but troublesome-to-students, concepts in *rigid body mechanics.* Its purpose is to better inform instructors in undergraduate dynamics courses so that they better understand the nuances and intricacies of student learning of this subject. Although much of a first course in dynamics covers Newtonian particle mechanics where the learning of the concepts could be assessed by the FCI, an important element to common dynamics courses is the introduction of rigid bodies of finite extent (i.e., non-point particles). For this topic there is little research on student misconceptions and no equivalent FCI that can be used to diagnose them. This means that it is hard to evaluate the success of any experimentation with instructional techniques.

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7 Halloun, I., and D. Hestenes, "Common-sense concepts about motion," *Am. J. Phys*. **53**, 1056 (1985).

8 Hake, R., ***Am. J. Phys.*** **66**, 64-74 (1998), or see *hitchcock.dlt.asu.edu/media2/cresmet/hake/.*

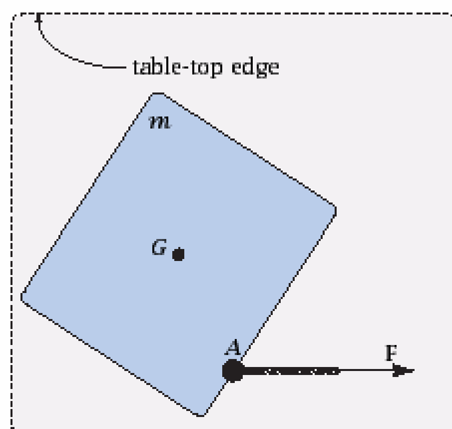
9 Hestenes, Wells and Swackhamer, *The Physics Teacher* **30**, 141 (1992) Revised edition available at *http://modeling.la.asu.edu/R&E/Research.html.*

This current work began by using a Delphi process to reach near-consensus agreement among a large number of dynamics instructors on the major concepts of the topic. This same group and process was used to reach near-agreement on which of the concepts students typically did poorly. This led to the definition of 11 concepts which were important but for which most students had severe difficulty.[10]

For these 11 concepts, questions were designed that might showcase misconceptions. The unique feature of the FCI is that the multiple choice possible answers, in addition to the one correct answer, had commonly held misconceptions as other possible answers. The task in the current research was to research the misconceptions on each of the concepts defined in the Delphi study.

Student focus groups conducted at three different universities were used in this research, followed up by wider-scale testing of students at additional universities. Early focus groups were asked to write out their responses to posed questions and to dialog with the focus group leaders about the questions. These responses produced material with which to refine the questions and to construct answers that expressed the students' misconceptions. These were then tested on more focus groups and further refined. After stability was reached, the questions were given at six universities to students who were just completing a dynamics course.

An Example Misconception: An original question posed to check students' understanding of the motion of rigid bodies was: You are currently driving down the highway in an automobile and you have to apply the brakes. When you do this, the front end of the auto tends to "nose-dive" or move closer to the road and the rear of the vehicle goes up. Why does this always happen? None of about 20 students in two separate focus groups gave anywhere near the correct answer. After a couple of iterations, the question was simplified to (see figure below): The box of mass *m* is initially at rest on smooth, frictionless, horizontal table. The box is pulled by a string that exerts a constant force **F** applied at the hinge at A. The orientation of the line of action of **F** is constant and the center of mass of the box is at G. Concerning the path of the mass center, G, of the box and how the orientation of the box will change, which of the following statements applies? a) Mass *m* will begin to rotate and point G will begin to move up and to the rights; b) Mass *m* will begin to rotate and point G will begin to move down and to the right; c) Mass *m* will begin to rotate and point G will begin to move to the right; d) Mass *m* will begin to rotate but G will not move; e) Mass *m* should not begin to rotate. In the large scale tests, only 25% of the students picked the correct answer (c), showing that, although they might have been able to write down the equations of motion and solve the problem, they had not yet connected the equations to the interpretation of a physical situation. They still preferred their pre-dynamics (mis)conceptions about the type of motion that would occur. More examples will covered in the paper.



The Development of an Assessment Instrument: The results are being used in the development of an easy-to-administer, easy-to-score assessment instrument that can reveal whether these common misconceptions have been affected by instruction. The instrument, called the Dynamics Concept Inventory (DCI) is patterned after the FCI. The current presentation, while showing Version 1.0 of the DCI, will highlight more the research findings on student misconceptions.

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[10] Gray, G. L., D. Evans, P. Cornwell, F. Costanzo, and B. Self, "Toward a nationwide dynamics concept inventory," ASEE Annual Conference, Nashville, TN (2003).