The Dynamics Concept Inventory Assessment Test: A Progress Report and Some Results

Gary L. Gray, Francesco Costanzo, Don Evans, Phillip Cornwell, Brian Self, Jill L. Lane

The Pennsylvania State University / The Pennsylvania State University / Arizona State University / Rose-Hulman Institute of Technology / United State Air Force Academy / The Pennsylvania State University

Abstract

Concept inventories are excellent instruments with which to validate the effectiveness of new teaching methodologies and curricular innovations. At the 2003 ASEE Annual Conference, we revealed that we were developing a Dynamics Concept Inventory (DCI) test and we presented our progress toward the creation of this test. Since that time, we have made substantial progress toward a release version of the DCI. In this paper, we will present the results of administering the DCI to over 450 students at a large public university and at a small private university and we will describe the final steps we have taken in getting to version 1.0 (the first public release) of the test.

Introduction: What is the DCI and Why are We Creating It

Concept inventories are an invaluable tool for the assessment of student learning and curricular innovations. Student misconceptions are not random, but are generally the result of a deficiency in their understanding of fundamental principles. The source of these misunderstandings, as identified by Clement [1] and others (see, for example references [2–7]), can be traced to deeply-seated preconceptions that make the complete understanding of fundamental principles very difficult. In order to create a new conceptual framework and to displace the existing one that has been ingrained over many years, new teaching methodologies have to be established. Concept inventories are an excellent instrument with which to validate the effectiveness of these new methodologies. At the 2003 ASEE Annual Conference, we revealed that we were developing a Dynamics Concept Inventory (DCI) test and we presented our progress toward the creation of this test [8]. In that paper, we described those concepts that were perceived by dynamics instructors to cause problems for students. Since that time, the authors have done extensive testing of the DCI and have completed its first public release (in January 2005).

The body of research knowledge on student learning of Newtonian mechanics, including both kinematics and kinetics, has become quite rich in the last 15 years, but, because of its newness, this knowledge generally remains unfamiliar to most instructors whether their academic home is in a physics department or an engineering department. Interestingly, it is not unusual for authors of papers on the *teaching* of mechanics in engineering education to refer to the history of how the *teaching* of the subject developed over the centuries since Newton and Euler published their general laws of motion (for a recent example, see Kraige [9]). However, this rich research literature on student *learning* of dynamics has yet to significantly influence either the presentation of the subject in textbooks or the emphasis and pedagogy used in the classroom. For the most part, the teaching of dynamics continues to be patterned after how instructors were taught when they were students, rather than being informed by research on learning. We believe that we are on the verge of seeing vast improvements in how much and how well students learn in this subject — we present this work with the hope that we can assist and even hasten this improvement.

History of the DCI

The impetus to create a DCI began at a Mini-conference on Undergraduate Education in Dynamics, Vibrations and Strength of Materials in San Antonio, Texas in September 2002. The purpose of the meeting was to discuss instructional innovations in these subjects, assessment instruments over and above the Force Concept Inventory (FCI) [10], found in the physics community, that would be beneficial to these subjects, and the extent to which these subjects might be brought closer together in delivery. Among other things, it was generally agreed that if we are to discuss the efficacy of innovations in mechanics education, we need a tool with which we can quantitatively assess each innovation. Based on the success of the FCI at assessing innovation in physics instruction, it was agreed that a DCI might provide the same sort of impetus for change and innovation in dynamics instruction. With all of this in mind, it was decided that a DCI team would be formed (for more of the history of the DCI, see [8]).

To identify dynamics concepts that students find difficult, we utilized a modified Delphi process [11] in which twenty-five veteran instructors of dynamics were asked to "describe the concepts in 2D rigid body dynamics that your students find difficult to understand".* They then provided a "brief description of common misunderstandings your students have about the concept". After the responses were collated and similar themes combined by the DCI team, the experts were asked to examine twenty-four different concepts. They rated each concept on (*a*) how important it is, and (*b*) whether or not their students understand the concept.

The twenty-four resulting concepts were then ranked according to importance *and* difficulty. As the goal was to design a thirty question test (similar to the FCI), ten concepts were selected so that each concept could be tested more than once. One of the top eleven most important concepts, "Work and energy are scalar quantities", was discarded because the DCI team felt that this concept was addressed in other concepts. This allowed us to include

*We limited our focus to 2D rigid body dynamics since: (*i*) everyone covers planar dynamics of rigid bodies, but a minority of schools cover 3D dynamics of rigid bodies, and (*ii*) we felt that the physics FCI adequately covers planar particle dynamics and the physics FCI has undergone substantial testing and refinement.

an additional concept for testing. Progress to this point was reported at the 2003 ASEE conference in Nashville [8].

Each DCI team member was then tasked to develop multiple choice questions for two of the concepts/misconceptions. The questions were critiqued by other members of the team and discussed until a consensus was reached. One of the concepts, "Dynamics are governed by 2nd order differential equations and have time dependent behavior", was ranked as the fourth most important by the Delphi process. Unfortunately, the team found that this concept was nearly impossible to assess using a multiple choice question, so the concept was dropped from the inventory. An additional reason for dropping this concept is that this concept is not taught directly or indirectly in the vast majority of curricula since it requires the coverage of ordinary differential equations, which is generally not a prerequisite for most sophomore-level dynamics courses. At this stage, the questions were ready to be tested on students.

Focus groups were held at three universities (two large public universities, Arizona State and Penn State, and a small private university, Rose-Hulman) of DCI team members. Although the original questions developed by the team members included distracters, in the first focus group, students were given questions without corresponding multiple choice answers so as to elicit distracters from the students. There is no better way to develop distracters than to use answers given by students themselves. In subsequent focus groups students were divided into two groups, some of whom were were administered questions with multiple choice answers and some of whom were asked to provide the answers as was done in the first focus groups. After the questions were answered by the students, the students were interviewed to determine their logic during the solution process. The DCI team also discovered whether or not the students found wording to be tricky or confusing; this resulted in rewording several different problems. Many of the student answers were then included as distracters in the multiple choice version of the DCI.

Finally, several beta tests were given at different universities across the nation. The scores from testing at three different institutions were presented at an ASEE Sectional meeting [12] and the ASEE Annual Conference [13]. Based on audience feedback at these two meetings and discussions with some of our colleagues, we decided to add "Coriolis acceleration" as one of the concepts/misconceptions in our inventory. This concept did appear in our original Delphi process and it was the second least understood concept rated by instructors, though the overall importance was low (17$^{\text{th}}$ most important out of 24 concepts). In the end the DCI team decided that Coriolis acceleration must be addressed in the DCI for it to be a true test of dynamics conceptual knowledge. To "work the bugs out" of these new questions, we gave them to students at Rose-Hulman Institute of Technology and we also conducted a focus group at Penn State University. We conducted the focus group in much the same format as those ran earlier in our development of the DCI. That is, we gave some of the students the questions with the multiple choice answers we created and we gave some of the students the questions (without answers) and we asked the students to supply the answers. This allowed us to not only "debug" the questions and our answers, but it also allowed us to confirm distracters and to discover new ones.

We should also add that the presence of friction in relation to rolling without slipping was also included as an important concept, even though it did not explicitly appear in the feedback we received from the Delphi process (though there were other concepts related to this one). In consultation with colleagues, the DCI team decided to include this concept since our experience (84 years combined experience teaching dynamics) has shown that students have substantial difficulty with rolling bodies in the presence of friction. In particular, it has been our experience that students have difficulty knowing the direction of the friction force between a rolling body and the surface on which it is rolling, both in the case of slipping and in the case of rolling without slip.

With all of the above in mind, the final eleven concepts/misconceptions we chose to include on the DCI are listed below.

1. Different points on a rigid body have different velocities and accelerations, which vary continuously.
2. If the net external force on a body is not zero, then the mass center must have an acceleration and it must be in the same direction as the force.
3. Angular velocities and angular accelerations are properties of the body as a whole and can vary with time.
4. Rigid bodies have both translational and rotational kinetic energy.
5. The angular momentum of a rigid body involves translational and rotational components and requires using some point as a reference.
6. Points an an object that is rolling without slip have velocities and acceleration that depend on the rolling without slip condition.
7. In general, the total mechanical energy is not conserved during an impact.
8. An object can have (a) nonzero acceleration and zero velocity or (b) nonzero velocity and no acceleration.
9. The inertia of a body affects its acceleration.
10. The direction of the friction force on a rolling rigid body is not related in a fixed way to the direction of rolling.
11. A particle has acceleration when it is moving with a relative velocity on a rotating object.

We note that there are four questions from the FCI on the DCI; these concepts are not given in the list above. In addition, some of the concepts listed above were tested using particle dynamics problems.

DCI Results from Two Very Different Schools

Version 0.96[†] of the DCI was administered during the fall 2003 semester to 166 students as a post-test at a very selective small private university (SPU) and to 147 students as a post-test at a large public university (LPU).[‡] In addition, it was administered during the spring 2004 semester to four sections of a dynamics class at a large public university (441 students as a pre-test and 310 post-test).

With regard to the fall 2003 administration of the test at the large public university, it should be noted that the course was taught in a traditional lecture format with two sections, each of which had a class size of roughly 110 students. By contrast, at the small private university, there were six sections of the course, each one containing between 25 and 30 students. At the small private university, instructors of these courses frequently give short quizzes at the beginning of class that often include concept type questions.

Contrary to how the course was managed in the fall 2003 semester, during the spring 2004 semester, the instructors at the large public university used the eInstruction Classroom Performance System (CPS)[§] throughout the semester to quiz the students on concepts. That is, about once every week and a half, the instructors would ask the students 3–4 concept questions with multiple choice answers and the students would respond using the CPS. Therefore, while the students were not directly asked the concept questions from the DCI, they were asked different questions on the same concepts addressed in the DCI. After the questions were answered, they were discussed with the students so that their misconceptions could be addressed. All of the results should be interpreted in light of this information.

A statistical analysis of the results from both universities is presented in the next section. We will then present an analysis of some of the questions on which students demonstrated some clear misconceptions. This will also give us an opportunity to present some of the questions on the DCI.

Statistical Analysis of Test Results

The DCI data for both the large public university and the small private university were statistically analyzed and the overall results are shown in Table 1. There is no pre-test data for either of the fall 2003 administrations of the DCI.

The results in Table 1 show the sample size N for each administration of the test, the mean, median, standard deviation, and Cronbach α, which is a measure of the reliability or

[†]The only major changes between version 0.96 and the current version 1.0 are the addition of the two questions involving the Coriolis component of acceleration and the removal of two FCI questions.

[‡]The DCI was administered at the start of the semester as a "pre-test" and at the end of the semester as a "post-test". There are no pre-test results for the small private university since the DCI was not given at the start of the term there.

[§]For further information, see <http://www.einstruction.com/>.

Table 1. Overall results for the tests administered at the LPU and SPU. N is the size of the sample.

Test	N	Mean (%)	Median (%)	Std Dev (%)	Cronbach α
LPU 2003 Post	147	32.1	31.8	15.0	0.640
LPU 2004 Pre	441	30.6	26.7	14.2	0.719
LPU 2004 Post	310	55.7	56.7	19.3	0.837
SPU 2003 Pre	172	34.9	—	—	—
SPU 2003 Post	166	63.9	63.6	16.8	0.730

internal consistency of a test. The most important numbers in this table for the purpose of validating the DCI are the Cronbach α's.

Two issues of primary importance in any testing situation are test content *validity* and test *reliability*. Content validity addresses how well a test covers the content of the subject matter that the test is designed to assess. That is, does the test cover the correct knowledge? Test reliability addresses whether the test will always elicit consistent and reliable responses even if questions are replaced with other similar questions or if the test is repeated using the same students.

The design team believes that the DCI questions that have now undergone testing cover the concepts important in rigid body dynamics. However, this question will not be completely settled until the test is more widely used by instructors—people still debate the validity of many of the questions on the FCI. The Delphi development process used to reach instructor/expert-based consensus on the concepts to be examined should have, if followed up appropriately, led to validity of the beta DCI content. The many focus groups used to validate the authenticity of the developed questions and associated answer sets also should have contributed to the validity of the beta DCI test items. The beta testing at the five participating institutions did uncover some minor areas that needed to be addressed—some were uncovered by students who wrote comments on their test packets, a few were noted by instructors who passed on some specific suggestions for minor changes, and a few others were noted by the DCI design team as they surveyed the distribution of student answers. The (unsolicited) comments returned from one of the participating instructors serves to verify the overall validity of the DCI questions, "This test seems to cover most of the concepts I stress and believe the students have trouble with."

To assess reliability, the DCI team analyzed the scores of the 754 participating students at the large public university and small private university described above. As shown in Tables 1 and 9, the mean score, median score, standard deviation, Cronbach α, and quartile scores were computed for the exams and each question on the exams. There was considerable variability in the average student scores among the three participating groups from two institutions, but the variability was consistent with that found in multiple-instructor FCI data [14].

The most frequently used internal consistency measurements are the Kuder-Richardson 20 (K-R20) and Cronbach α and either measure provides a conservative estimate of the reliability of a set of test results [15–18]. Cronbach's α has the advantage of applying to weighted or nondichotomous data. Cronbach's α estimates the proportion of variance in test scores that can be attributed to *true* score variance. In other words, Cronbach α is used to estimate the proportion of variance that is systematic or consistent in a set of test scores. Cronbach α can range from 0.0 (if none of the variance is consistent) to 1.0 (if all the variance is consistent). So, for example, if the Cronbach α for a set of scores turns out to be 0.90, one generally interprets that as meaning that the test is 90% reliable. Nunnaly [18] indicates that a Cronbach α of 0.7 or greater indicates a test with acceptable reliability.

With this in mind and referring to Table 1, we make the following observations.

- The DCI passes Nunnaly's tests for reliability. In fact, as you will see in Table 9, each individual question exhibits strong reliability (we only list Cronbach's α for those DCI questions discussed in this paper).
- While not immediately relevant to the DCI, the change in the mean (or median) post-test scores from 2003 (32.1%) to 2004 (55.7%) at the large public university, seems to indicate that even a minimal teaching of concepts makes might make a dramatic difference in conceptual knowledge. Of course, we don't have the pre-test data for the LPU 2003 pre-test, so we don't know what gains were achieved for that class. On the other hand, the population of students is such that the pre-test scores for LPU 2003 are likely the same as the pre-test scores for LPU 2004. As you can see, the pre-test mean for the LPU 2004 pre-test is essentially the same as the *post*-test mean for the LPU 2003. Analysis of the post-tests compared not only the differences in the overall means between groups at the large public university, but also the means within the eleven content areas (subscales or concepts) contained on the inventory. Results indicated that the mean score of the spring 2004 students was significantly higher ($t = -10.345$, $p < 0.001$) than the fall 2003 students.[¶] Further analysis of the mean scores within each subscale indicated that *the spring 2004 students outperformed the fall 2003 students in all of the content areas, with the means being significantly higher in 10 of the 11 content areas* (see Table 2).

Questions Highlighting Clear Misconceptions

A number of questions resulted in a vast majority of students selecting the same incorrect answer on the pretest, thus indicating a strong misconception. We now present six of the questions from the DCI that elicited strong misconceptions for the administration of the DCI at the small private university during fall 2003 and the large public university during spring 2004. The quartile and Cronbach α results for each of these questions for both the large public university and small private university and for both 2003 and 2004 are shown

[¶]The t-test is a statistical test used to determine if there is any significance difference between the means of different samples of data. The "p value" is the probability that the observed value of the test statistic is equal to or greater than the actual computed value "t". The smaller the p value, the more significant the result. See [19].

Table 2. Post-inventory subscales at a large public university (fall 2003 vs. spring 2004).

Subscale (concept)	t-test	Significance (p)
A realistic impact entails loss of mechanical energy	−3.141	0.002
Angular momentum of a rigid body	−3.426	0.001
Balance of work and energy for a rigid body	−1.502	0.134[a]
$\mathbf{F} = m\mathbf{a}$ for rigid bodies	−5.231	< 0.001
Free-body diagram of a rolling rigid body with friction	−10.172	< 0.001
Kinetic energy of a rigid body	−8.902	< 0.001
Relation between friction and velocity	−2.131	0.034
Relation between inertia and acceleration	−3.277	0.001
Rigid body kinematics	−6.470	< 0.001
Vectorial nature of acceleration	−4.227	< 0.001
Vectorial nature of velocity	−6.608	< 0.001

[a] The *only* significance greater than 0.05, indicating the only subscale that does not show significant difference between means. That is, while the spring 2004 students had a higher mean in this subscale, it was not *significantly* higher.

in Table 9, which has been placed at the end of the paper.

Question 13, shown in Fig. 1, had over 85% of students selecting the same distracter on the pre-test (see Table 3). Although gains were made by the time the post-test was given,

Table 3. LPU and SPU answers for Q13. The correct answer is highlighted.

	Large Public University		Small Private University	
Answer	Pre-Test %	Post-Test %	Pre-Test %	Post-Test %
(a)	1.4	1.9	0.0	0.0
(b)	5.5	20.3	4.2	7.2
(c)	4.6	56.1	5.5	36.1
(d)	2.3	1.9	0.0	0.0
(e)	86.2	19.7	90.9	56.6

there were clearly still a large number of students, 44% at the large public university and 64% at the small private university, who still had misconceptions regarding this problem. It is the authors' belief that the primary misconception comes from a strong student belief that "tension = weight". Whether this misconception comes from previous classes, such as Statics, is not clear. More students from the large public university improved on this problem than from the small private university.

Questions 21 and 22 were on the topic of rigid body kinematics (i.e., different points on a rigid body have different velocities and accelerations). These questions are shown in Fig. 2 and the answers given by the students are presented in Tables 4 and 5. Question 21 is testing whether or not students understand that the wheel shown in Fig. 2 is undergoing

Question 13

Both systems shown have massless and frictionless pulleys. On the left, a 10 N weight and a 50 N weight are connected by an inextensible rope. On the right, a constant 50 N force pulls on the rope. Which of the following statements is true immediately after unlocking the pulleys?

(a) In both cases, the acceleration of the 10 N blocks will be equal to zero.

(b) The 10 N block on the left will have the larger upward acceleration.

(c) The 10 N block on the right will have the larger upward acceleration.

(d) The tension in the rope on the left system is 40 N.

(e) In both cases, the 10 N block will have the same upward acceleration.

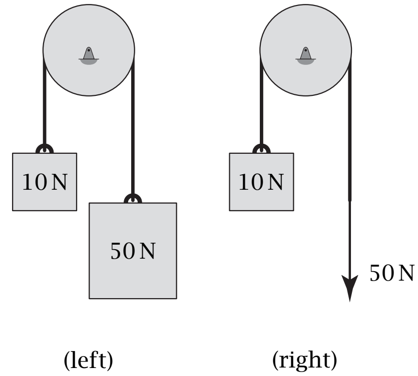


Figure 1. Question 13 of the DCI is designed to test students' understanding of inertia and the idea that the tension in a rope does not equal the weight suspended from it if the weight is accelerating.

Table 4. LPU and SPU answers for Q21. The correct answer is highlighted.

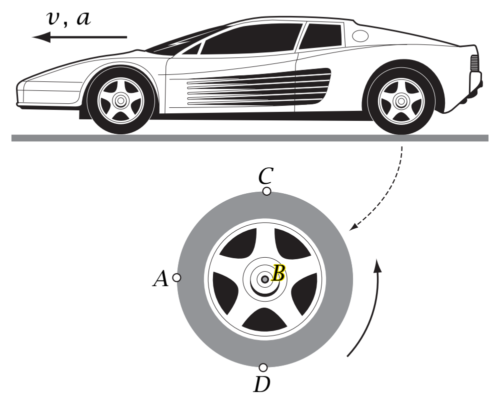
	Large Public University		Small Private University	
Answer	Pre-Test %	Post-Test %	Pre-Test %	Post-Test %
(a)	6.0	4.6	3.6	1.2
(b)	12.2	58.2	18.2	71.7
(c)	72.1	26.6	75.2	22.9
(d)	6.9	8.6	3.0	3.0
(e)	2.8	2.0	0.6	1.2

general plane motion and therefore that the velocity of point A will be a combination of the rotation of the wheel about the contact point D and the translation of the wheel. On the pre-test over 70% of students selected the same distracter on Question 21. This answer was that the velocity would be perpendicular to the wheel as if it were undergoing fixed axis rotation about its center B. By the post-test, however, approximately 60%–70% of the students were selecting the correct answer. On Question 22, the students were asked which point on a wheel that is rolling without slipping has the smallest speed. Only 17% (large public university) to 30% (small private university) of the students originally got the answer correct. On the pre-test the two answers selected most often, which accounted for more than 70% of the students, corresponded to the cases of the wheel undergoing fixed axis rotation or translation. By the post-test, over 75% of students were selecting the correct answer.

One question that had very small gains and on which the students did very poorly was Question 26, which is shown in Fig. 3. On the pre-test only about 10% of the students

Questions 21 & 22

A rear-wheel drive car moves with speed v and acceleration a to the left as shown in the figure. The tires do not slip on the road.



Question 21

What is the direction of the velocity of point A attached to the tire?

(a) ⟵ (b) ↙ (c) ↓ (d) ↘ (e) ↑

Question 22

Of the points A, B, C, and D shown on the tire, which has the smallest speed?

(a) A (b) B (c) C (d) D (e) They all have the same speed.

Figure 2. Questions 21 and 22 from the DCI are designed to test students' understanding of rigid body kinematics. That is, that the velocities of different points on a rigid body undergoing general plane motion are different.

Table 5. LPU and SPU answers for Q22. The correct answer is highlighted.

	Large Public University		Small Private University	
Answer	Pre-Test %	Post-Test %	Pre-Test %	Post-Test %
(a)	2.1	0.3	1.2	0.0
(b)	53.2	15.5	49.1	16.3
(c)	2.5	2.0	0.6	1.2
(d)	16.9	77.0	28.5	75.9
(e)	25.2	5.3	21.2	6.6

got the question correct (see Table 6). The concept this question is testing is that of angular momentum of a rigid body, one that students clearly do not understand well, even after the course.‖ The question was intended to test if students recognized that the angular momentum about any point is a combination of the angular momentum of the object about its center of mass plus the moment of the linear momentum about the point about which the angular momentum is being determined. For students at the large public university there were actually negative gains and, although there were slight gains for the small private university, the vast majority of students, 81%, still missed this problem. One possible explanation for the poor performance is that typically not much time is spent on impulse-momentum methods for rigid bodies in dynamics courses. It is possible that the problem was confusing, but since the majority of students selected point B to be the point

‖The instructors at the large public university covered the topic angular momentum of a rigid body at the end of the semester and did not have the opportunity to use the CPS system to ask any concept questions based on this topic.

Question 26

A boomerang is thrown and, at an instant in time, its velocity and angular velocity are as shown ($v > 0$, $\omega > 0$). At this instant, about which labeled point does the boomerang have the *minimum* angular momentum (i.e., a negative value is *smaller* than zero)? Assume that angular momentum is defined to be positive in the clockwise direction.

(a) *A*

(b) *B*

(c) *C*

(d) *D*

(e) The angular momentum is the same about all four points.

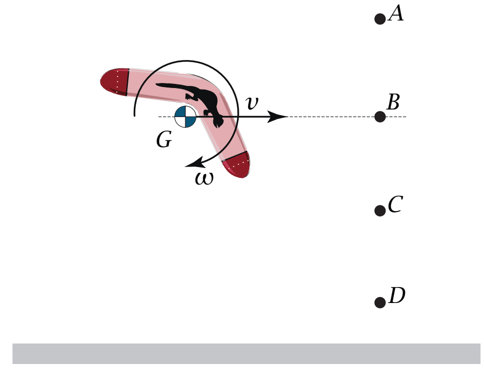


Figure 3. Question 26 on the DCI is designed to test students' understanding of the angular momentum of a rigid body.

Table 6. LPU and SPU answers for Q26. The correct answer is highlighted.

	Large Public University		Small Private University	
Answer	Pre-Test %	Post-Test %	Pre-Test %	Post-Test %
(a)	11.4	9.1	9.7	18.1
(b)	48.6	66.2	69.7	68.1
(c)	4.5	2.0	1.2	0.6
(d)	16.0	12.2	10.3	7.2
(e)	19.5	10.5	9.7	6.0

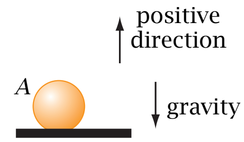
about which the angular momentum is zero, there does seem to be a lack of understanding with regard to how the total angular momentum of a rigid body is determined.

Another question that had only moderate gains, on the order of 13%, was Question 9, which is shown in Fig. 4, and for which the student responses are given in Table 7. This problem was designed to test students' understanding that an object can have zero velocity and non-zero acceleration. On the pre-test, the two most commonly chosen answers were (a), i.e., that the acceleration is zero, indicating the misconception that if the velocity is zero then the acceleration must also be zero, and (d), that the acceleration was equal to $-g$ (the acceleration due to gravity), indicating the misconception that gravity is an acceleration rather than the force of attraction between two masses. As can be seen from Table 7, by the end of the course, these misconceptions were still present in a majority of the students.

Finally, a question testing the students' understanding of the kinetic energy of rigid bodies is Question 10, which is shown in Fig. 5 and for which the students' responses are tabulated in Table 8. In this problem students are asked to compare the kinetic energy of two platforms, one that is translating and rotating and the other that is simply translating. Less than

Question 9

A ball is thrown straight up and it falls back to the ground. In the position A shown, the ball has hit the ground on its first of many bounces and its center of mass has reached its lowest position. Given the positive direction shown, please choose the correct answer describing the acceleration a of the ball's center of mass at this point.



(a) $a = 0$,

(b) $a < 0$,

(c) $a > 0$,

(d) $a = -g$,

(e) not enough information given.

Figure 4. Question 9 on the DCI is designed to test students' understanding of the independence of the sign of velocity and acceleration.

Table 7. LPU and SPU answers for Q9. The correct answer is highlighted.

	Large Public University		Small Private University	
Answer	Pre-Test %	Post-Test %	Pre-Test %	Post-Test %
(a)	51.7	38.6	43.0	37.3
(b)	7.1	4.9	4.2	3.6
(c)	16.5	29.5	28.5	42.2
(d)	23.6	23.7	17.0	16.3
(e)	1.1	3.2	7.3	0.6

40% of students got this problem correct on the pre-test, and the most common distracter selected was that the two platforms had the same kinetic energy. Large gains were made on the problem on the post-test, indicating that by the end of the course students have a much better understanding of the idea that the total kinetic energy of a rigid body is a combination of its translational kinetic energy and its rotational kinetic energy.

Table 8. LPU and SPU answers for Q10. The correct answer is highlighted.

	Large Public University		Small Private University	
Answer	Pre-Test %	Post-Test %	Pre-Test %	Post-Test %
(a)	13.2	4.2	11.5	5.4
(b)	37.1	84.7	28.5	72.9
(c)	37.4	7.5	32.7	16.9
(d)	3.0	1.3	0.0	0.0
(e)	9.3	2.3	26.7	4.8

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.

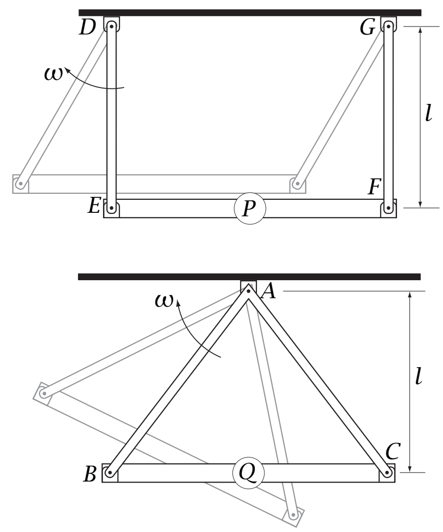


Figure 5. Question 10 on the DCI is designed to test students' understanding of the kinetic energy of a rigid body.

Summary

We have provided an update on the current state of the Dynamics Concept Inventory and we consider this paper to be the first public announcement that version 1.0 of the DCI is ready for widespread use. We have shown that the DCI is a reliable test (via Cronbach's α) that tests eleven different concepts from rigid body dynamics (and even more concepts from particle dynamics). In addition, we have demonstrated the substantial gains that can be achieved in the "standard" dynamics course when concepts are presented in an unobtrusive manner (using only 10–15 minutes per week of class time). It is our hope that the DCI can become a test used nationally to assess curricular innovations and to measure gains in conceptual understanding of engineering students. We encourage you to contact any of the authors to provide feedback on the DCI.

The Dynamics Concept Inventory web site can be found at `<http://www.esm.psu.edu/dci/>` and the DCI, along with some guidelines for its use, are available there.

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Table 9. Quartile and Cronback α Results for the problems discussed in the forthcoming section entitled "Questions Highlighting Clear Misconceptions".

Test	Problem	Quartile (%) 1	2	3	4	Cronbach α
LPU 2003 Post	9	3.57	14.3	22.0	41.7	0.617
	10	28.6	45.2	48.8	50.0	0.643
	13	17.9	26.2	29.3	61.1	0.622
	21	0.00	16.7	12.2	41.7	0.607
	22	35.7	50.0	68.3	77.8	0.623
	26	3.57	4.76	9.76	11.4	0.638
LPU 2004 Pre	9	5.04	13.0	13.9	34.5	0.710
	10	31.6	40.8	42.1	34.9	0.734
	13	2.54	4.00	3.70	8.18	0.719
	21	5.93	5.05	15.9	22.0	0.716
	22	5.13	9.09	15.9	37.6	0.708
	26	11.4	9.38	10.8	13.9	0.722
LPU 2004 Post	9	15.7	11.9	30.4	61.8	0.834
	10	66.3	91.0	93.5	88.2	0.837
	13	33.7	53.7	54.3	86.8	0.833
	21	31.3	47.8	68.5	83.8	0.832
	22	54.2	76.1	87.0	86.8	0.836
	26	4.82	5.97	8.70	16.2	0.838
SPU 2003 Post	9	19.0	25.5	60.0	68.1	0.710
	10	47.6	70.2	76.7	95.7	0.711
	13	16.7	36.2	26.7	59.6	0.720
	21	45.2	68.1	76.7	95.7	0.707
	22	42.9	76.6	86.7	97.9	0.700
	26	0.00	14.9	13.3	40.4	0.709

References

[1] Clement, J. (1982) "Students' Preconceptions in Introductory Mechanics," *American Journal of Physics*, **50**(1), pp. 66–71.

[2] Brna, P. (1987) "Confronting Dynamics Miconceptions," *Instructional Science*, **16**, pp. 351–379.

[3] Clement, J. (1987) "Overcoming Students' Misconceptions in Physics: The Role of Anchoring Intuitions and Analogical Validity," in *Proceedings of the Second International Seminar on Misconceptions and Educational Strategies in Science and Mechanics* (J. D. Novak, ed.), vol. 3, Cornell University, Ithaca, NY, pp. 84–97.

[4] McCloskey, M. (1983) "Intuitive Physics," *Scientific American*, **248**(4), pp. 122–130.

[5] McDermott, L. C. (1984) "Research on Conceptual Understanding in Mechanics," *Physics Today*, pp. 24–32.

[6] Shannon, B. (1976) "Aristotelianism, Newtonianism and the Physics of the Layman," *Perception*, **5**, pp. 241–243.

[7] White, B. Y. (1983) "Sources of Difficulty in Understanding Newtonian Dynamics," *Cognitive Science*, **7**, pp. 41–65.

[8] Gray, G. L., D. Evans, P. Cornwell, F. Costanzo, and B. Self (2003) "Toward a Nationwide Dynamics Concept Inventory Assessment Test," in *Proceedings of the 2003 American Society for Engineering Education Annual Conference*, vol. Session 1168, American Society for Engineering Education, Nashville, TN.

[9] Kraige, G. (2002) "The Role of the Kinetic Diagram in the Teaching of Introductory Rigid Body Dynamics—Past, Present, and Future," in *Proceedings of the 2002 American Society for Engineering Education Annual Conference and Exposition*, vol. Session 2268, American Society for Engineering Education, Montréal, Canada.

[10] Hestenes, D., M. Wells, and G. Swackhamer (1992) "Force Concept Inventory," *The Physics Teacher*, **30**, pp. 141–158.

[11] Clayton, M. (1997) "Delphi: A Technique to Harness Expert Opinion for Critical Decision-Making Tasks in Education," *Educational Psychology*, **17**, pp. 373–386.

[12] Self, B. P., G. L. Gray, D. Evans, P. Cornwell, F. Costanzo, and A. Ruina (2004) "Progress on the Dynamics Concept Inventory," in *Rocky Mountain Section Meeting of the American Society for Engineering Education*, Laramie, Wyoming, presentation only.

[13] Gray, G. L., D. Evans, F. Costanzo, P. Cornwell, and B. Self (2004) "Progress on the Dynamics Concept Inventory," in *American Society for Engineering Education Annual Conference*, Salt Lake City, Utah, presentation only.

[14] Hake, R. R. (1998) "Interactive-Engagement Versus Traditional Methods: A Six-Thousand-Student Survey of Mechanics Test Data for Introductory Physics Courses," *American Journal of Physics*, **66**(1), pp. 64–74.

[15] Cortina, J. M. (1993) "What is Coefficient Alpha? An Examination of Theory and Applications," *Journal of Applied Psychology*, **78**(1), pp. 98–104.

[16] Cronbach, L. J. (1951) "Coefficient Alpha and the Internal Structure of Tests," *Psychometrika*, **16**, pp. 297–334.

[17] Miller, M. B. (1995) "Coefficient Alpha: A Basic Introduction from the Perspectives of Classical Test Theory and Structural Equation Modeling," *Structural Equation Modeling*, **2**(3), pp. 255–273.

[18] Nunnaly, J. C. (1978) *Psychometric Theory*, 2nd ed., McGraw-Hill, New York.

[19] Freedman, D., R. Pisani, and R. Purves (1997) *Statistics*, 3rd ed., W. W. Norton & Company, New York.

Biographies

GARY L. GRAY came to Penn State in 1994 and is an Associate Professor of Engineering Science and Mechanics. He earned a Ph.D. degree in Engineering Mechanics from the University of Wisconsin–Madison in 1993. His research interests include the mechanics of nanostructures, dynamics of mechanical systems, the application of dynamical systems theory, and engineering education.

FRANCESCO COSTANZO came to Penn State in 1995 and is an Associate Professor of Engineering Science and Mechanics. He earned a Ph.D. degree in Aerospace Engineering from the Texas A&M University in 1993. His research interests include the mechanics of nanostructures, the dynamic crack propagation in thermoelastic materials, and engineering education.

D. L. EVANS is Emeritus Professor of Engineering in Mechanical Engineering and past Director of the Center for Research in Education on Science, Mathematics, Engineering and Technology (CRESMET) at Arizona State University. He holds a Ph.D. degree in Mechanical Engineering from Northwestern University, earned in 1967. His current interests include research in teaching and learning in science, mathematics, engineering and technology in from kindergarten through graduate school.

PHILLIP CORNWELL is a Professor of Mechanical Engineering at Rose-Hulman Institute of Technology. He received his B.S. from Texas Tech University in 1985 and his M.A. and Ph.D. from Princeton University in 1987 and 1989 respectively. His present interests include structural dynamics, structural health monitoring, and undergraduate engineering education.

BRIAN P. SELF is an Associate Professor in the Engineering Mechanics Department at the United States Air Force Academy. He obtained a Ph.D. in Bioengineering at the University of Utah and an MS in Engineering Mechanics at Virginia Tech. Research interests include biomechanics, aerospace physiology, and improvements in engineering education.

JILL L. LANE is a Research Associate at the Schreyer Institute for Teaching Excellence and an Affiliate Assistant Professor of Instructional Systems at Penn State. She holds a D.Ed. in Instructional Systems from Penn State. Her research interests include sustainability of innovations in higher education, the impact of changes to the teaching and learning process, and the effects of integrating research into the college classroom using inquiry-based approaches to learning.