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The Dynamics Concept Inventory (DCI) – The Past, Present, and Future

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The Dynamics Concept Inventory (DCI) – The Past, Present, and Future

Abstract

The Dynamics Concept Inventory (DCI) was developed over 15 years ago as a tool for instructors teaching Dynamics to assess their students' gains in conceptual understanding of the material. Since its initial release, there have been hundreds of downloads of the instrument, and the initial papers presenting the instrument have been referenced over 100 times. In this paper, we will 1) present a brief history of the development of the DCI, 2) evaluate the ways it has been used since its release with the hope of encouraging more engineering faculty members to use it, 3) summarize results from those who have used it, and 4) present plans for future development and distribution.

History of the DCI

The idea for a DCI began at a Mini-Conference on Undergraduate Education in Dynamics, Vibrations, and Strength of Materials that occurred in September 2002 [1]. The Force Concept Inventory (FCI) had been around since the early 1990's and was recognized as being successful in spurring innovation in physics education [2]. At this meeting, participants agreed that a Dynamics Concept Inventory could potentially provide the same benefits for dynamics instruction. A DCI team was formed and first met at the *Concept Inventory Workshop* at the *2002 Frontiers in Education Conference* in Boston (November 2002). The NSF-funded Foundation Coalition was a key driver behind the development of the DCI and other concept inventories.

The DCI was developed using a modified Delphi process to identify concepts in dynamics that (a) were important and (b) that students find difficult. Twenty-five experienced instructors in dynamics were asked to "describe the concepts in dynamics that your students find difficult to understand." A total of 24 different concepts were identified from this process, and then the faculty members were asked to rank each of these in terms of importance and difficulty. Based on this feedback, 29 multiple-choice questions were developed that focus on 11 concepts. Initial testing of the questions took place at three universities and involved having students answer open-ended questions. Their answers were used to help develop plausible distractors. Focus groups were held on the DCI to refine the questions and the distractors, and finally a Beta test was given to students at the beginning and at the end of a dynamics course. Additionally, we received permission to put four problems from the physics Force Concept Inventory on the DCI to see how students did on prerequisite material. The DCI was released to the public in 2005.

Two issues examined in the statistical analysis of the results were test content validity and test reliability. The Cronbach α test was used to assess the reliability of the DCI when it was first administered at a large public school and at a small private school. For more details on the history, composition, reliability, and validity of the DCI see [1, 3].

A quick overview of the DCI

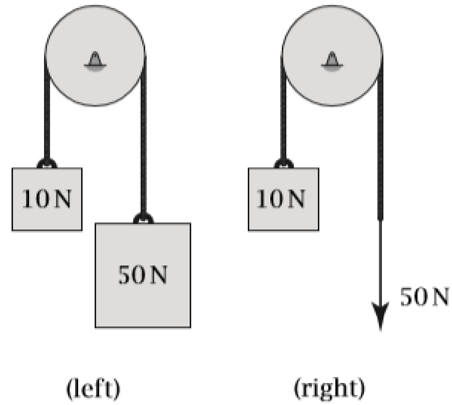
The final eleven concepts/misconceptions we chose to include on the DCI are:

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 on an object that is rolling without slip have velocities and accelerations 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.

As examples, two DCI questions are shown in Figures 1 and 2. Figure 1 shows a problem 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. Figure 2 shows a problem designed to test students' understanding of the kinetic energy of a rigid body. The problem shown in Figure 1 is one that over 90% of students typically miss in the pre-test when they choose answer e. Only about 50% of students typically get this problem correct on the post-test shoring that it is very difficult to change the strong student belief that "tension = weight." Unfortunately, this misconception is often reinforced in Statics classes. For the problem shown in Figure 2, typically only 30% to 40% of students answer the problem correctly in the pre-test, but this improves significantly in the post-test with 80% to 90% getting it correct. For a detailed discussion of the results from these questions, and other DCI questions, see [3].

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.

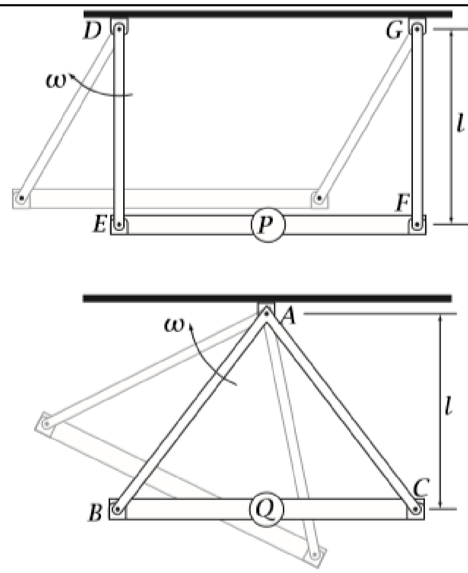
(d) The tension in the rope on the left system is 40 N.

(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.

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 2 - Question 10 of the DCI is designed to test students' understanding of the kinetic energy of a rigid body.

Distribution

The test was released to the public in 2005 using the website https://sites.esm.psu.edu/dci/, and a hardcopy is still available from this site. The downloadable DCI is password protected, and we only send it to individuals we can confirm are faculty members. Hundreds of faculty members from universities in the United States and abroad have requested the solution key. We request that users send us feedback and/or results, but to be honest, we have received very little feedback or data on the instrument from users. Recently, we have added the DCI to the AIChE Concept Warehouse, http://jimi.cbee.oregonstate.edu/concept_warehouse. We hope this will make it easier for faculty members to use the DCI, and for us to collect a robust set of data from the Concept Warehouse to perform additional reliability and validity analysis. Ultimately, we want to use this data to improve the instrument.

Usage/references over the past 15 years

It is clear that the DCI is being used based on the number of requests for the solution key and the number of references to the original DCI papers. The first DCI paper was published in 2003 [1] and, based on Google scholar, has been referenced about 50 times, and the update in 2005 [3] has been referenced about 107 times. From the engineering education literature, most references to the DCI can be put in four main categories:

1. Assessment of curriculum modifications or innovations
2. Assessing the efficacy of course modifications. The modifications were usually introduced into a course to improve conceptual understanding.
3. Pointing out the limitations of the DCI or in the context of developing an abbreviated dynamics concept inventory.
4. Referenced in the paper but not discussed or used. These papers usually reference the DCI as one of many concept inventories.

An example of a paper that used the DCI to assess a curriculum modification involved the integration of a statics course and a dynamics course [4]. The largest category, by far, was the assessment of changes made to a course. These included the introduction of concept-oriented example problems [5], video games [6], "real-world problems" [7], inquiry-based learning activities (IBLAs) [8-9], in-class concept demonstrations [10], visualization using SolidWorks animations [11], deliberate practice [12], systematic problem-solving strategies [13], and the use of Twitter [14]. Other studies used the DCI to assess whether or not including hardware and simple experimentation in the class improves conceptual understanding [15,16]. Some of the studies involved comparing the efficacy of two approaches; for example, comparing a live interactive broadcast to lecture-style classes [17] or structured homework assignments compared to online homework [18].

A much smaller number of papers presented feedback or commented on the DCI itself. Ref. [19] points out limitations of concept inventories to measure students' abilities to identify and apply concepts in more complicated situations or to assess their ability to apply and transfer knowledge. The most detailed evaluation of the DCI used classical test theory [20,21]. The investigators conclude that it is well suited for low stakes formative assessment but may have limitations for high stakes uses. They also make some suggestions to improve the instrument both by removing some items and by adding additional “high quality” items. In this paper they present an abbreviated dynamics concept inventory, aDCI, which they claim is more amenable to in-class implementation than the much longer full DCI [22]. This inventory is an 11-question subset of the original 29-question DCI.

Proposed future development

As mentioned previously, we are encouraging users to implement the DCI using the Concept Warehouse. This tool was originally developed for use in the Chemical Engineering community and contains hundreds of concept questions (named ConcepTests after Mazur’s coining of the phrase [23]). A currently funded project is adding content in both statics and dynamics to the Concept Warehouse, and there are already over 100 ConcepTests uploaded for a variety of mechanics topics.

Instructors can peruse Concept Warehouse capabilities and apply for a faculty account at https://jimi.cbee.oregonstate.edu/concept_warehouse/. After their instructor status is verified, they can access concept questions, several concept inventories, and various instructional tools. Additionally, they can provide feedback on ConcepTests and upload their own ConcepTests to the site. The Concept Warehouse can then be used to assign questions online before class or as a classroom response system that collects and shows student responses. It can be downloaded for use in class or on quizzes, and is compatible with computers as well as various smart devices.

We have run pilot tests of the CW at seven different institutions, with 16 different instructors, 43 different classes, and 1650 students. Instructors simply upload their class roster to the site, and then an email is autogenerated telling the students to create a login and password. Instructors can then assign Concept Inventories (there are currently inventories for Dynamics, Fluid Dynamics, Chemistry, Heat Transfer, Materials Science, Statics, and Thermodynamics), ConcepTests, and Instructional Tools (currently for Thermodynamics and Chemical Engineering, but being developed for Statics and Dynamics). The webpage showing how instructors access the DCI on the Concept Warehouse is shown in Figure 3.

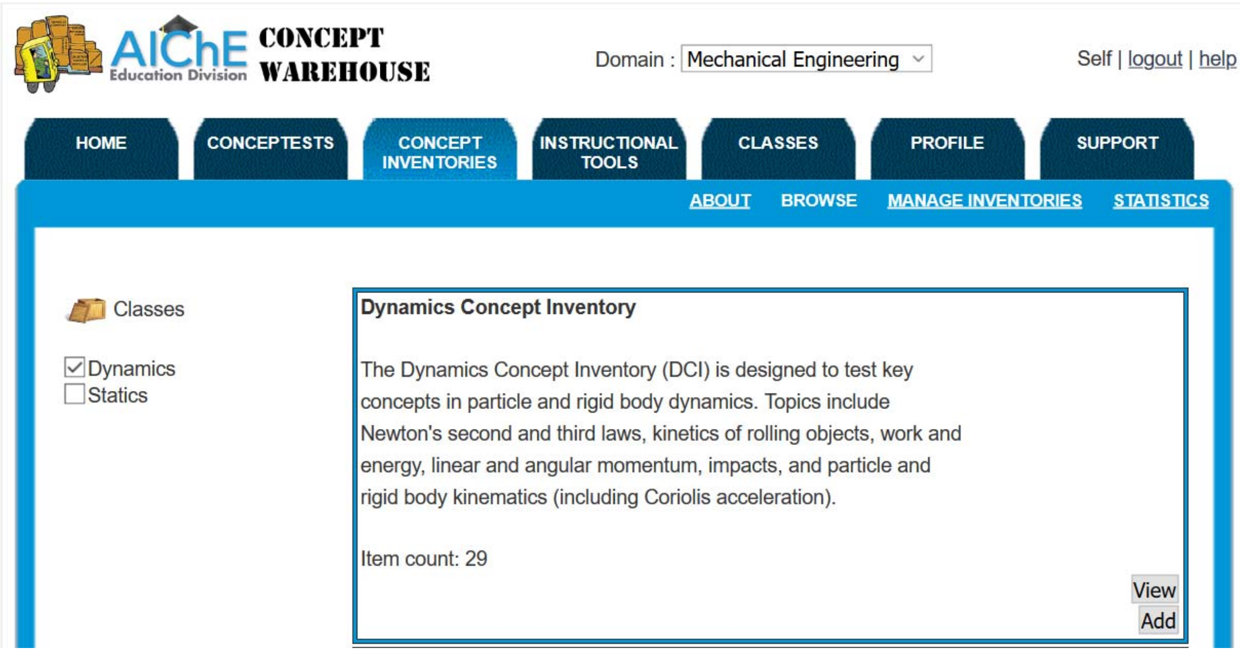


Figure 3. Concept Inventory tab on the Concept Warehouse website.

After students take the DCI on the CW, instructors are provided with an assessment of how their students did. They can look at individual questions (see Figure 4) to see the number of students choosing each answer, as well as a report of how students did on the targeted concepts (Figure 5). Finally, instructors can compare how students did on different offerings of the DCI (e.g., pre-class and post-class assessments). Data can be downloaded as a CSV for each administration of the concept inventory.

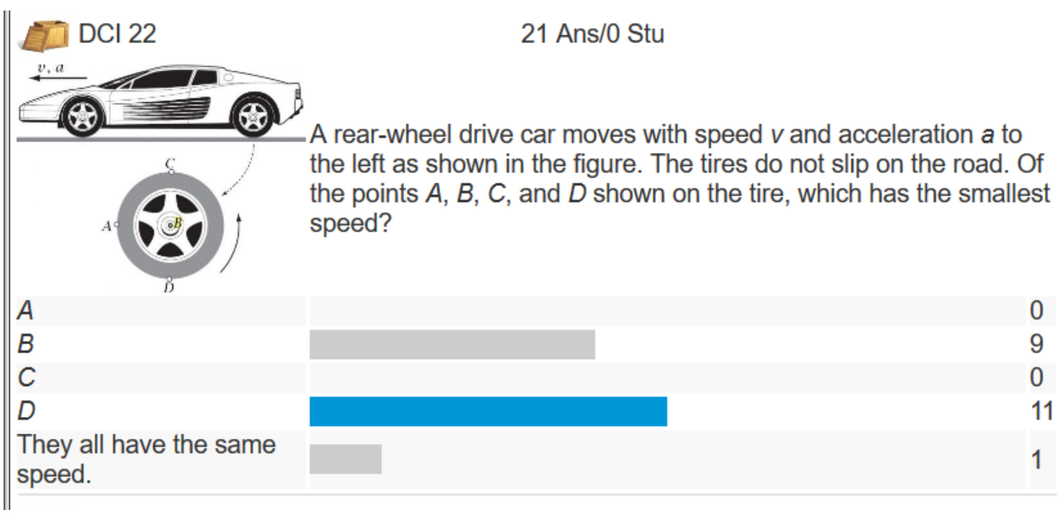


Figure 4. Example of student data provided to instructor for problem 22 on the DCI.

Results

Scale	Number Questions	Valid Students*	Correct
Interaction force between two objects	2	14	96.4%
Points on a rigid body	2	16	18.8%
Angular velocities & accelerations	2	14	25.0%
Particle on a rotating object	2	14	7.1%
External force on a rigid body	5	14	42.9%
Object moving in a curved path	1	14	35.7%
Acceleration vs. velocity for an object	1	14	21.4%
Rigid body kinetic energy	1	14	57.1%
Inertia of a body	3	14	26.2%
Mechanical energy on impact	2	14	46.4%
Object rolling without slip	3	13	30.8%
Rigid body angular momentum	2	13	11.5%
Friction force on a rolling body	2	14	28.6%
Friction force between two objects	1	14	14.3%
All Scales	**29**	**13**	**34.5%**

*The number of students who answered all of the questions in the scale.
A total of 16 students answered at least one question in the inventory.

Figure 5. Example feedback for instructors showing how students did on different concepts on the DCI.

By moving to the Concept Warehouse, we hope to accomplish a number of different goals. The first is that it will allow us to capture data from various users, which in turn will provide us with better difficulty and reliability data. These data could indicate that certain questions should be replaced or rewritten if we decide to create an updated version of the instrument. Using the CW will also make it easier for faculty members administering the DCI by providing them with data analytics that can be downloaded in Excel. The CW can also be used for research purposes. We can look at students who take multiple Concept Inventories, see if students who answer certain ConcepTests do better on Concept Inventory questions, and add in targeted survey questions.

We also hope that faculty members who use the DCI will be attracted to the wealth of resources that the CW has to offer. As more instructors use the formative questions posed as ConcepTests, we will collect data on how students perform on these questions, and potentially develop a revised version of the DCI or establish a newer Concept Inventory that focuses on rigid bodies. Instructors can even upload their own ConcepTests, and the community of users can provide comments on the questions and give suggestions for improvements. The current DCI has several Force Concept Inventory questions, but students do so well on most of these that they do not provide much differentiation [20], so we may consider dropping these from a future version of the instrument. Additionally, factor analysis has shown that not all of the questions map well to our intended concepts, and we need more questions for each concept. If a new DCI version 2 is developed, we will take into account this factor analysis. We may also fine tune the concepts we choose to cover on the exam.

Conclusions

In this paper, we presented a brief history of the development of the DCI and an overview of the concepts it covers. In the 15 years from when it was first released, hundreds of instructors have requested to us it and nearly 160 authors have cited it in their work. The instrument has been primarily used to assess a variety of changes made to Dynamics courses around the country. The DCI was recently moved to the Concept Warehouse, a free online repository of concept questions, instructional tools, and concept inventories that was developed by the Chemical Engineering community and is being expanded into mechanic courses. It is our hope that the use of the CW this will make it easier for faculty members to implement the DCI in their courses, and for us to collect data on the instrument so we can improve it in the future.

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