AC 2007-394: USING CONCEPT-ORIENTED EXAMPLE PROBLEMS TO IMPROVE STUDENT PERFORMANCE IN A TRADITIONAL DYNAMICS COURSE

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Using Concept Oriented Example Problems to Improve Student Performance in a Traditional Dynamics Course

Abstract

Three years of assessment of student performance in CIVL 301 (Engineering Mechanics: Dynamics) has indicated that students are missing many key concepts that are required to develop and solve engineering problems involving course material. Subjective faculty assessment results in 2004 (based on two exams with three long problems each) indicated that students were unprepared to solve multi-step dynamics problems, because most could not appropriately setup the problems as a result of a lack of understanding of key concepts covered in dynamics. In response to this concern, the professor changed the exam format in 2005 to 43 multiple choice questions that assess the students' understanding of "key concepts". Nationally recognized concept inventories were also used to assess student performance and to determine if the subjective assessment conclusion was indeed correct. Both objective assessment instruments indicated clearly that students at The Citadel are not learning many of the key concepts needed to solve engineering problems and that the problem may be a direct result of the presentation format used by the course instructor (traditional lectures with long problems only) and the similar presentation format used by the course textbook. A hypothesis was developed in 2005 that student performance may improve if the course material is presented in more of a "concept oriented" format with short (1 to 2 line) example problems that illustrate this material. Hence, in 2006 the author elected to modify the conclusion of each chapter's material presentation by presenting short concept only problems to improve student understanding of the key subject material. No other changes to the course material or presentation format were made in 2006. The objective exams show a marked improvement in student understanding of course material that appears to be a direct result of the conclusion problems illustrating key concepts. This paper presents the evolution of assessment used in CIVL 301, example problems illustrating key concepts of dynamics, and the quantified student performance improvement in 2006 relative to previous years.

Introduction

The use of concept inventory exams to assess student knowledge of key course material and effectiveness of faculty instruction is not new. The work of Halloun and Hestenes[1,2] performed in the mid 1980s has formed the basis for most modern research in this area. The research team[1,2,3,4] developed a concept inventory for physics that was based on a conceptual understanding of the key concepts covered in the course. The key difference between the concept inventory exam developed by the team and typical course exams used by physics instructors is that the concept inventory exam used "word problems" that examined the students intuitive understanding of the material and did not require mathematical calculations to reach the conclusions. Based on these efforts modern research teams under the umbrella Foundation

Coallition have developed concept inventories for thermodynamics[5], strengths of materials[6], signals and systems[7], electromagnetics, circuits, fluid mechanics, and materials.

Gray et al.[8] describes the initial development of the Dynamics Concept Inventory (DCI) test and Gray et al.[9] presents the history of the DCI, beta testing for the exam as performed at a small private university and a large public university, and a discussion regarding the first public release of the DCI. The Citadel has obtained a copy of the DCI and has used the exam for course assessment since the Fall of 2005.

Evolution of Instruction and Assessment Methods for Dynamics at The Citadel

Instructional methods and assessment tools used at The Citadel for CIVL 301 Dynamics are presented in Table 1. For all six semesters, the same professor taught the course using the same lecture material and the same example problems taken from the course textbook. The class was consistently taught utilizing direct instruction without variations in the presentation style. The same homework assignments were also given each year. Subjective faculty assessment results in 2004 (based on two exams with three long problems each) indicated that students were unprepared to solve longer dynamics problems, because most could not appropriately setup the problems as a result of a lack of understanding of key concepts covered in dynamics.

Table 1. Assessment Instruments used for CIVL 301 at The Citadel from Summer 2004 to Fall 2006.

Semester	Instructional Method	Assessment Tools (Excluding Homework)
Summer 2004	Direct Instruction using lengthy problems that illustrate many key concepts simultaneously	Midterm Exam (3 Long Problems), Final Exam (3 Problems), 5 Part Multiple Choice WebCT Problem for Each Course Goal
Fall 2004	Same as Summer 2004	Same as Summer 2004
Summer 2005	Same as Summer 2004	Same as Summer 2004
Fall 2005	Same as Summer 2004	DCI, 13 Problem Short Concepts Multiple Choice Midterm Exam, 30 Problem Short Concepts Multiple Choice Final Exam, 5 Part Multiple Choice WebCT Problem for Each Course Goal
Summer 2006	Same as Summer 2004	Same as Fall 2005
Fall 2006	Same as Summer 2004 followed by a series of short key concept problems for each course goal	Same as Fall 2005 but replacing the 5 Part Multiple Choice WebCT Problem with 1 Multiple Choice Embedded Indicator Problem in Accordance with the Department's Policy

In response to this concern, the professor changed the exam format in 2005 to 43 multiple choice questions (13 on midterm, 30 on final) that assess the students' understanding of "key concepts". The exams were not returned to the students to keep the questions confidential so that they could be reused every year. For the first time, the DCI was also used to assess student performance and to determine if the subjective assessment conclusion was indeed correct. Both objective assessment instruments (Fall 2005 and Summer 2006) indicated clearly that students at The Citadel are not learning many of the key concepts needed to solve engineering problems and that the problem may be a direct result of the presentation format used by the course instructor (traditional lectures with long problems only) and the similar presentation format used by the course textbook. A hypothesis was developed as part of the 2005 ABET Course Assessment Report that student performance may improve, if the course material is presented in more of a "concept oriented" format, with short (1 to 2 line) example problems that illustrate this material. Hence, in 2006 the author elected to modify the conclusion of each chapter's material presentation by presenting short "concept only" problems to improve student understanding of the key subject matter. The problems were different than those used on the midterm and final exam, but tested the same key concepts. An important difference between the key concept problems given by the professor on the midterm and the DCI is that the professor's midterm and final are all quantitative in nature. They usually involve only one or two lines of calculations as illustrated in the following section of this paper. One final note, in the Summer of 2006, the faculty in the Civil & Environmental Engineering Department at The Citadel voted to have all classes use embedded indicators for assessment. Hence, the dynamics WebCT online quizzes presented in Table 1 were modified in the Fall of 2006 to contain only one problem that serves as the embedded indicator for each course goal.

Traditional Dynamics Problems, DCI Problems, and Quantitative Key Concept Problems

To illustrate the difference between traditional dynamics problems, DCI type problems, and key concept problems used at the Citadel, an example is now presented for the wheel rolling as shown in Figure 1.

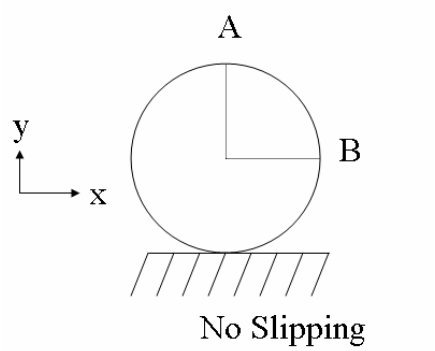

Figure 1. Rolling Wheel Used to Illustrate Various Types of Problems Used to Assess Knowledge of Key Concepts in Dynamics.

Traditional Problem
For the wheel shown in Problem 1, the wheel's radius is 2 ft, the instantaneous velocity at the center of the wheel is 4 ft/s to the right. Express the velocity of points A and B as vectors using the coordinate system indicated on the figure.

DCI Type Problem
For the wheel shown in Problem 1, what is the direction of the velocity of point B at the instant shown if the wheel is rolling to the right without slipping?
(A) Straight Down (B) Straight Up (C) Down and to the Right (D) To the Right

Key Concept Type Problem Used on Midterm and Final Exam
For the wheel shown in Problem 1, what is the magnitude of the velocity (ft/s) of point B at the instant shown if the wheel (radius = 2 ft) is rolling to the right at 4 ft/s without slipping?
(A) 1.41 (B) 2.83 (C) 4.24 (D) 5.66

Results of Adding Key Concept Problems to Instructional Method

As previously discussed, the only instructional method change used for CIVL 301 Dynamics since 2004 was the use of key concept problems at the end of each chapter (Fall 2006 only). These problems were similar in form to the example problem shown in Figure 1, but different than the actual midterm exam and final exam problems. Although the key concept problems given at the end of each chapter covered the same concepts as tested on the exams, they were not multiple choice in format. Rather, the students developed their own solutions and a senior student (Cadet Blake Mitchell) worked the problems with the students. This work was performed outside of the normal classroom schedule. All students participated, but they were not given extra credit for completing the problems. Student participation was based on their understanding that participation might improve their score on the exams. The purpose of the senior student is two fold. First, the instructor wanted to provide a "student teaching student" forum for the review problems and the senior student had mastered all course goals the previous year and was prepared, by the instructor, for the reviews. Secondly, based on the assessment results to date, a future goal for the instructor is to slowly implement an active learning pedagogy for this dynamics course. Direct instruction in senior design courses has been more successful than it has been in this junior level course.

Table 2 presents student scores on the DCI, midterm, and final exams for each semester. The DCI was given both as a pre-test and a post-test and both scores are shown. Regarding the DCI, only minor gains of statistical merit can be shown. Also, the scores shown for the DCI do not include three questions that are concepts not covered in Dynamics at The Citadel. However, as discussed in Gray et al.[9], students at the two beta testing schools had a similar performance (pre and post) prior to the instructor using concept inventory practice problems in the course. In that study, the small private university regularly used daily quizzes that were concept type questions and the large public university used an external online concept performance monitoring program called the eInstruction Classroom Performance System. In both cases, students at those colleges ". . . were asked different questions on the same concepts addressed in the DCI." The authors also state, "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." The two schools used in the beta study showed an increase from around 30% pre-test to around 60% post-test in the study. Citadel students did not show such an increase for several possible reasons:

- Citadel students are not given any practice questions in DCI format – Although students were given many concept review problems in numerical format, students were not given DCI format questions other than those on the pretest. The difference between the two types of questions is presented in the previous section.
- Dynamics at The Citadel does not cover rigid body impact and momentum (in lieu of elementary vibrations) which is covered on the DCI
- Direct instruction is currently used at The Citadel – The literature suggests that classes such as dynamics might be best taught using an active learning approach. Hence, the next step to improve student learning appears to be implementing and assessing various pedagogical approaches for this course.

Performance on the DCI at The Citadel appears to have improved only slightly as a result of key concept questions used during the Fall of 2006. Continual effort will be made to improve student performance on the DCI.

Table 2. Assessment scores on various tests.

Semester	Number of Students	DCI Pre-test	DCI Post-test	Improvement	Midterm Exam	Final Exam
Fall 2005	26	25%	32%	7%	62%	47%
Summer 2006	28	27%	32%	5%	56%	54%
Fall 2006	27	26%	38%	12%	69%	70%

On the contrary, the addition of key concept questions has a marked impact on student performance on the midterm and final exams. Although not normalized, the raw scores for the Fall 2006 are significantly higher than in previous semesters. It should be noted that based on the exam difficulty and the presence of distracters on the midterm and final exams, the professor has determined that a class average of 55% meets expectations on this exam and the Fall 2006 score of 70% is outstanding.

Course goals and associated bloom's taxonomy levels for Dynamics are summarized as follows:

1) Developing governing equations of motion and using differential and integral calculus to solve engineering problems (synthesis)
2) Applying particle kinematics to solve engineering problems (application)
3) Applying Newton's Second Law and energy and momentum methods to solve engineering problems (application)
4) Applying kinematics of rigid bodies to solve engineering problems (application)
5) Applying kinetics of rigid bodies to solve engineering problems (application)
6) Solving introductory free and forced vibration problems (knowledge)

Although the impact of the key concept problems is evident for all course goals, the greatest impact has been on course goal number 5. Specifically, Fall 2006 student performance (60% correct) on this goal has increased from the previous average (36% correct) as assessed on the final exam. This is paramount since this goal has been the biggest concern presented in the instructor's assessment report each time the current faculty member has taught the course. It appears that the key concept problems have helped students overcome misconceptions regarding rigid body kinetics.

The use of multiple choice questions on the midterm and final exams may or may not test students at the higher levels of Bloom's taxonomy. The authors feel that for the levels considered in this course, the questions on the exams are appropriately written to achieve this objective. A similar argument can be made about the PE exams that should be testing candidates at higher levels of Bloom's taxonomy.

Summary and Conclusions

The following summary statements can be made:

- A small change to the pedagogical method to include a key concept review can improve student understanding of the fundamental concepts of the material.
- Improvements to the DCI score is not consistent with previously published data. Work should be done on the use of scaffolding throughout the class on the percent improvement pre and post utilizing the DCI test.

Since Citadel students have not improved their scores on the DCI exam significantly in response to key concept problems, the logical next step is to introduce intuitive questions as part of the Summer 2007 course. Depending on the results of this approach, the next step will be to remove some of the traditional dynamics problems from the lecture material in lieu of more conceptual problems. Finally, the ultimate goal is to teach the course using an active learning approach in lieu of the direct instruction approach currently used to teach dynamics at The Citadel.

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