AC 2012-3773: CHALLENGE-BASED INSTRUCTION IN MEASUREMENTS AND INSTRUMENTATION

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Challenge-Based-Instruction in Measurements and Instrumentation Course

Abstract

This paper describes a newly developed Challenge-Based-Instruction (CBI) course for Measurements and Instrumentation (M&I) in mechanical engineering. This form of instruction relies on asking questions during lecture and is one of the best ways to incite curiosity among the students. This curiosity compels the students to find the answer to the question posed. The nature of the questions can propel them into a state of inquisitiveness and hence provide the instructor the right time and opportunity to present the course material. The CBI method of instruction thoroughly exploits this natural tendency with the goal of fostering committed and deeper learning rather than surface learning. For the M&I course, a series of challenge questions were developed. For example, the challenge question, "How can you make a given paper glider glide the longest distance possible?", can be used to introduce the concept of aerodynamic drag and hence lead to various ways in which aerodynamic drag can be quantified through pressure and velocity measurements. This challenge-question gives the instructor an opportunity to embed in the minds of students the importance and the concepts of pressure and velocity measurements. A series of such challenge-questions were developed for the various chapters in the syllabus of M&I.

Several metrics were used to measure student learning including; homework, in-class-quizzes (both formative and summative), laboratory exercises, and midterm and final exams. The "average performance scores" of the students from two different semesters, one with the CBI method of instruction and one without, were compared. An examination of the scores in lecture-quizzes and midterm exams yielded an effect size of 0.82 and 0.73 respectively. Furthermore, the average scores of the students during the semester with CBI were higher by about 12% as compared to the semester without CBI. The introduction of the CBI method of instruction in the M&I course was therefore promising as it created a conducive atmosphere for classroom discussion, and increased student participation and interest in both the lectures as well as the laboratory sessions. Furthermore, after the challenge-question was presented, the interaction of the instructor with the students showed an increase in student participation during the lectures

and the students were more inclined to relate the concepts learned during the class and in the laboratory sessions with real-life examples.

Introduction

Engineering measurements are an important part of everyday life. They range from routine measurements with some implications to a person (e.g. the temperature of an outdoor thermometer to choose appropriate clothing for the day, the volume of fuel in an automobile, measuring cups to yield correct ingredients in cooking, etc.) to highly complex measurements such as state-of-the-art Particle Image Velocimetry (PIV). When the measurements are routine, the outcome of these measurements is not important enough to merit much attention to features like improved accuracy and precision. However, in complex measurements, when the stakes become greater, the selection of measurement equipment and techniques and the interpretation of measured data can demand considerable attention. CBI for MECE 3320 teaches students the importance of measurements in these complex situations. The technique helps students develop an experimental test plan and use the measurement system so that the engineer can easily interpret the measured data and be confident in its meaning. The study by Pandy et al. [1] which showed that the CBI approach, as compared to a traditional approach, increased the students' conceptual knowledge and the ability to transfer the knowledge to new situations further encouraged the design of CBI modules for the MECE 3320 course. Furthermore, an exhaustive study by Barr et al. [2] showed that the CBI method of approach was more appealing to a vast number of students than the traditional method of teaching.

Challenge-Based-Instruction

CBI is designed on the theory that optimal learning occurs from an instruction that is *knowledge centered, learner centered, assessment centered,* and *community centered* (Bransford, Brown and Cocking, [3]). These *centerednesses* are all incorporated into the *legacy cycle* which provides the backbone of our implementation of CBI. The legacy cycle consists of five different phases (Figure 1). It begins with the *generation of ideas* phase. This is an activity that encourages students to display their current knowledge, ideas and perceptions with regard to a challenge question. The *generation of ideas* begins with the students writing a narrative and formulating their initial thoughts on the challenge question presented to them followed by whole-group brainstorming and sharing of ideas. This is the phase of the legacy cycle where the students, based on their existing knowledge and information, explore different ideas connected with the challenge question. Once the ideas are generated, the students are presented with *multiple perspectives* related to the challenge question from various outside sources. The possible sources for multiple perspectives include outside experts in the field (live or through video), internet website information, textbook excerpts, clips from video and magazine articles. All these sources provide a basic insight into the challenge posed to the students. With this new insight, the students are encouraged to reexamine their ideas. The students then enter the *research and revise* phase. In this phase, the students are provided with additional information as needed and are encouraged to seek more information. This may be in the form of lecture, readings, website, etc. The students then revise their original ideas based on this new information. The possible venues where they can *research and revise* their ideas include in-class lectures, textbook and other readings and also from among the sources they sought during the multiple perspectives phase.

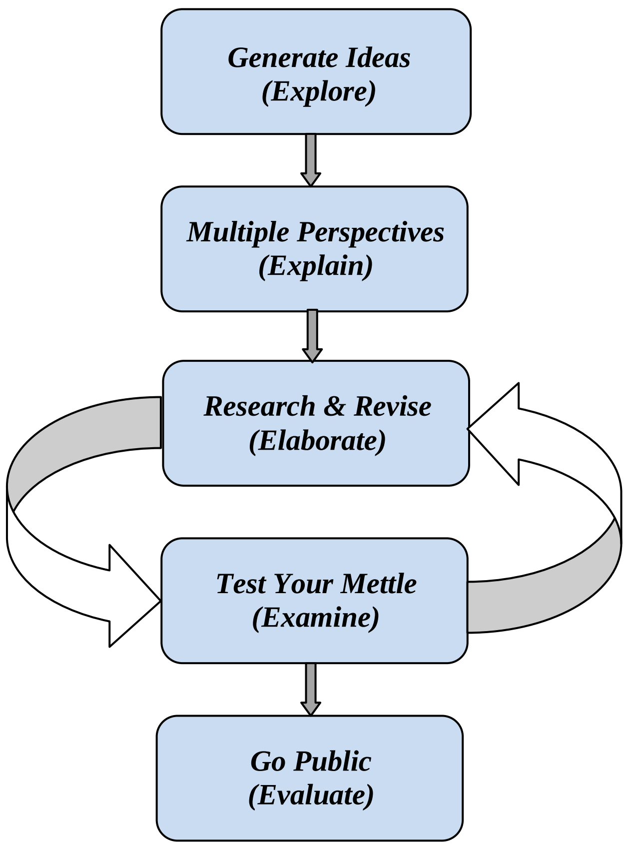

Figure 1. Different phases of the Legacy Cycle.

After the students complete the *research and revise* phase, they try out their ideas in the *test your mettle* phase. This phase is a formative feedback activity. If the "test results" are not positive, the students can return to the research and revise phase. The formative feedback in the *test your mettle* phase can occur from other students and/or the instructor in the context of posters, essays, practice tests, etc. Depending on the success of *test your mettle*, students can cycle back to the research and revise phase multiple number of times. Once successful, the students present their final conclusions in the *go public* phase. This phase can include summative assessment activities which can include tests, oral presentations and posters/projects, etc. The following section describes selected CBI modules designed for MECE 3320 course based on the Legacy Cycle described above.

Method

In designing the CBI modules for MECE 3320 course, the key considerations that are taken into account are (Giorgio and Brophy, [4]):

a) selection of learning objectives

b) preparation, integration, and delivery of teaching materials such as PowerPoint slides, teaching notes, informative video clips, etc.

c) integration of formative and summative assessments

The introduction of CBI into the MECE 3320 course begins with the administration of a pre-test covering the various learning objectives in the entire course. Each of the CBI modules is introduced to the students through the different phases of the legacy cycle. At the end of the course, a post-test consisting of the same questions as the pre-test is administered to the students to gauge their understanding of the subject material and their grasp of the learning objectives. The CBI modules for MECE 3320 are divided into five topical areas covering temperature, pressure, velocity, flow and force measurements. The concepts behind these measurements are presented to the students through the following challenges described below. In presenting these topics and challenges to the students, the appropriate technical background is delivered by progression through different phases of the legacy cycle.

a) *The paper glider*: The paper glider challenge is "How will you make the paper glider glide the longest distance possible?" The student is initially provided with a regular drinking straw and two strips of paper. Using these simple materials, the student is challenged to build a paper glider that can glide the longest distance possible. The width of the paper strips, their angle and position on the straw dictate the glide-distance of the paper glider. While going through this challenge, students learn the importance of aerodynamic drag and its effect on the glide-distance of the paper glider. The students then quantify the drag using pressure and velocity measurements. At the end of this module, students not only learn the importance of pressure and velocity measurements but are also exposed to the theory of sampling and data acquisition systems.

b) *The air-conditioning engineer*: The air-conditioner engineer challenge is "Where in a residence will you place a thermostat and how will you mount it on the wall?" In this challenge, the students learn the concepts behind temperature measuring devices and sensors. The students are encouraged to think of different factors that can cause the temperature of the sensor in a thermostat to be different from the air temperature and therefore cause discomfort for the occupants of the house. They are provided the necessary information on how the thermal capacitance of the temperature sensor can affect the operation of the thermostat. They are also encouraged to think about the practical aspects of installing and using thermostats in homes. The practical aspects include asking the students to come up with reasons as to why thermostats are typically set $5^{o}C$ higher in the air conditioning season. At the end of this module, the students not only deepen their knowledge and broaden their perspectives with regard to temperature measuring devices but also learn the intricate concepts of thermometry, thermoelectric temperature measurements and physical errors in temperature measurements.

c) *The race track engineer*: The race track engineer challenge is concerned with pressure measurements involving a race car. The challenges are, "What are the forces a car is subjected to when it moves at high speeds along a race track?" and "How will you measure the pressure changes on the exterior surfaces of a car as it moves along the race track?" Wall pressure taps are often used to sense surface pressure, such as those on cars, and are connected to transducers by connecting tubing. In this module, the students are asked to design the preferred diameter of the tubing to measure pressure changes on a car as it moves along a track. The students are encouraged to choose between different tube lengths and what implications each of the lengths have on the pressure measurement. At the end of this module, the students learn the concepts of pressure transducers, calibration, pressure measurement in moving fluids, design and installation of pressure measurement systems, the dynamic response of pressure measuring devices and fluid velocity measurements.

d) *The cantilever beam scale*: The cantilever beam scale challenge is concerned with the measurement of strain and consequently, force/thrust/weight. The challenges are "Do you achieve more accuracy by having more sensors on a cantilever beam scale?" and "Will the arrangement of the sensors on the beam affect the accuracy of the cantilever scale?" In this module, the students are challenged to think about the effect of the placement of sensors on a cantilever beam to measure the weight of an object. They are also encouraged to think about the effect of the number of sensors in measuring a given weight placed on the cantilever beam. Through this design, the students learn the concepts of stress and strain, strain gauges and their arrangement, signal conditioning and data acquisition.

e) *Sensors in your car*: This module allows students to revisit the basic measurement of physical quantities like time and distance. Challenge questions are posed related to car sensors. Further challenge questions can be derived from the initial questions. For example: How do you know your car's speedometer is accurate? What methods can be used to measure your car's speed? How do you estimate your car's gas mileage? To what extent do you believe these measurements can be different from true values? What factors can affect these measurements? How can sensor manufacturers access NIST or other standard providing institution to determine the accuracy of their products? While addressing these challenges, students can be exposed to various measurement devices such as stopwatch, map, GPS, speed radar, video camera, etc. Assessing the "goodness" of the measurement leads to the concept of uncertainty and calibration.

"Effect size" was used as a metric to quantify the difference between two groups, one with CBI and another without. The effect size is given by the following equation (Coe [5]):

$$Effect\ \ Size = \frac{\text{Mean of experimental group} - \text{Mean of control group}}{\text{Pooled standard deviation}}$$

Effect size is a numerical quantity that represents the degree to which a particular method of intervention is effective. It is a statistical measure of the significance of the difference. An underlying assumption is that the test scores of the control and experimental groups are normally distributed. Research has shown that an effect size of 0.4 and below indicates the educational intervention is, in general, less than effective (Hattie [6]). An effect size of 1.0 signifies an increase of one standard deviation and generally indicates that the educational intervention has had a substantial effect on the experimental group.

Results

A preliminary introduction of CBI into the M&I course during Spring 2010 showed an increase in student participation during the lecture. The assimilation and understanding of the concepts presented through the challenge-questions was also evident from the regular lecture quizzes and also during the laboratory sessions of the M&I course. The students were also better able to understand and appreciate the corresponding experiments that were related to the challenge-questions during the laboratory sessions. Furthermore, it was observed that, after the challenge-question was presented, students were more inclined to relate the concepts learned during the class and in the laboratory sessions with real-life examples—the data, however, was only qualitative. In order to have a quantitative assessment, data from the Fall 2011 semester was considered in which CBI was implemented into many of the teaching modules.

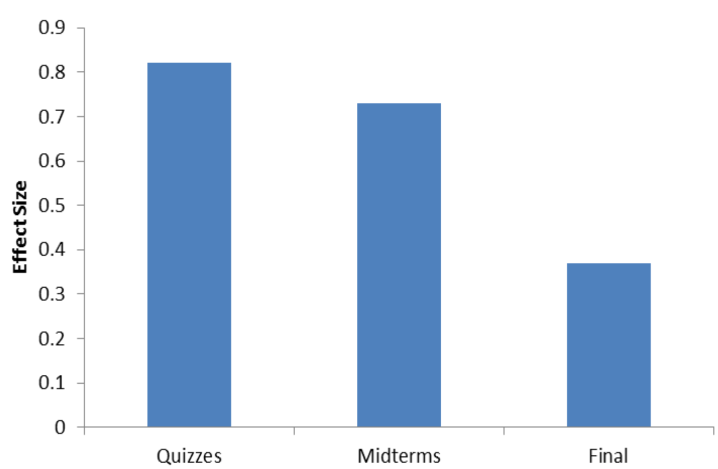

Figure 1. Effect sizes for the three test scores in Measurements & Instrumentation course

This data was compared with other semesters' data in which CBI was not implemented. Analysis of the two sets of data yielded an effect size of 0.82 for in-class quizzes and 0.73 for midterm exams. The effect size for the final exams was found to be 0.37. Figure 1 shows the effect sizes for the three test scores. The standard deviations in the test scores of quizzes and exams were found to be similar for the two groups under consideration.

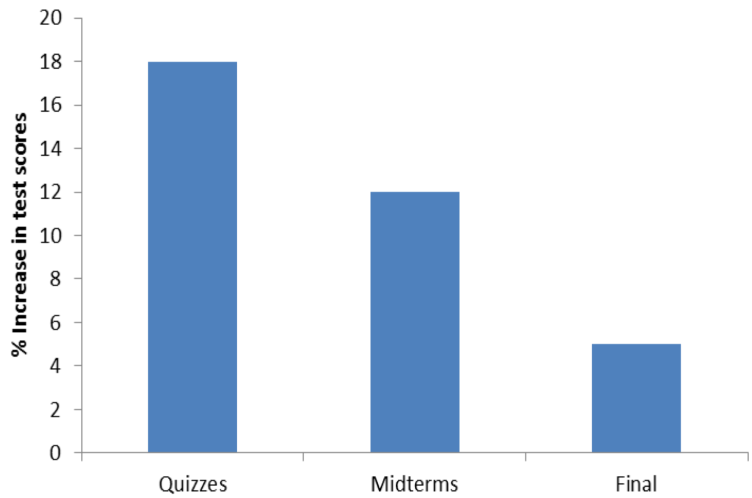

Figure 2. Percentage increase in the test scores as a result of CBI

Furthermore, analysis of the test scores also showed that, on average, the CBI group's scores were about 12% higher than the non-CBI group (Figure 2). It was found that the CBI had the most effect in in-class quizzes followed by midterm exams and finals.

Conclusions

The introduction of the CBI method of instruction in the M&I course was promising as it created a conducive atmosphere for classroom discussion, increased student participation and interest in both the lectures as well as the laboratory sessions. Analysis of the test scores of in-class quizzes, midterm and final exams yielded effect sizes of 0.82, 0.73 and 0.37, respectively. Further analysis is required to understand as to why the effect size decreased as one progressed towards the final exam. It is possible that teaching modules that cover a wide range of topics and chapters in the textbook may overwhelm the students when it comes to the final exam. To explore this issue, more challenge questions will be added in the following semesters and the teaching modules will be broken down to smaller units. Each of these subunits will again begin with a challenge-question as described earlier, based on which, the concepts of M&I will be presented to the students. Quantitative results which will include pre and post tests, pre and post-affect surveys, will also be administered to the students to gauge the effectiveness of challenge-based learning in MECE 3320.

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