AC 2010-832: USING THE DYNAMICS CONCEPTS INVENTORY AS A CONTINUOUS PROCESS IMPROVEMENT METRIC FOR IMPROVING STUDENT LEARNING OUTCOMES

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Using the Dynamics Concepts Inventory as a Continuous Process Improvement Metric for Improving Student Learning Outcomes

Abstract

Having objective metrics to assess student assimilation of the concepts on which the study of Dynamics is based makes it possible to implement Continuous Process Improvement on the teaching of this junior-level dynamics class. Over seven semesters, the Dynamics Concepts Inventory was used as a pre- and post-course assessment of student conceptual understanding in a Dynamics class taught through live interactive broadcast from a remote location. Self-assessment through DCI scores, a self-developed questionnaire, and student assessments have led to changes in lecture style, textbook, and in-class concept demonstrations. However, only small improvements in average DCI scores have occurred. A reduction in the number of unanswered questions from the pre- to post-course Inventories indicates that students feel more confident in their knowledge of dynamics concepts, even if the average score improvement pre- to post- is only two correct responses out of a total of 29 questions on the Inventory. Having the DCI pre-course assessment has enabled troubleshooting of bimodal grade distributions in classes with poorly prepared students. Employing the DCI as a CPI tool has created an environment in which distractions from the dynamics material, like the broadcast environment and textbook selection, can be minimized while effective demonstrations and class discussions can be developed. This paper discusses the results of employing the DCI as a CPI tool along with changes made to curriculum delivery. The next increment of changes to content delivery is also discussed.

Introduction

Continuous Process Improvement, CPI, is an established industry practice with the goals of reducing variability in a product, eliminating non-value added steps from processes, and improving customer satisfaction. CPI is one of the results of application of statistical process control, which originated in Bell Telephone Laboratories in 1924 by Dr. Walter Shewhart[1]. ABET evaluation criteria espoused application of continuous improvement philosophies to Engineering Education with the Engineering Criteria 2000 published in 1996[2] and continue to propagate the application with the current standards[3]. The practice has become so ingrained in American industry that in May 2006, all US Department of Defense (DoD) activities were required to implement CPI and the Continuous Process Improvement Transformation Guidebook was published[4]. The personnel conducting this study were trained in CPI through DoD activities and brought that experience into the educational community from industry.

Maguad describes a customer-oriented business model for universities that identifies the industry that hires graduates as the customer and students as the product[5]. Adopting this model is necessary to allow the application of CPI to a university activity. In the current environment where basic engineering skills and education are commodities[6], universities, like competitive industries, must be efficient in creating a product their customer finds valuable. In the case of engineering education, the processes of developing *basic* skills in students must be efficient for the program to remain affordable and to create time for developing the advanced skills in students that industry finds valuable and that are necessary to differentiate ones own engineers from those trained elsewhere.

Efficient educational processes can be created through the application of CPI by: 1) reducing variability in learning outcomes by having a higher percentage of students demonstrate the skills and learning outcomes required to pass the class; 2) eliminating non-value-added activities from the learning process for both students and faculty in and out of the classroom; and 3) improving the satisfaction both of the industry customer by producing graduates with stronger skills who have more confidence in their basic engineering skills, and of the student products with their educational experiences. The internal faculty customer satisfaction with their professionalism and quality of product should also be improved as a by-product of the CPI application.

A number of models for CPI are available in the literature and each practitioner develops his or her own style of implementation. All of the models share some assumptions: relevant data that describes the process and quality of the product can be measured and documented; only those factors that negatively influence the measured outcome of the process should be changed; and the factors influencing the product quality can either be controlled or the process can be made robust to variation of those factors. Two different models were employed in this implementation: 1) the DMAIC model explained in The Continuous Process Improvement Transformation Guidebook[5]: Define, Measure, Analyze, Improve and Control, and 2) the ADDIE model used in instruction design[7]: Analyze, Design, Develop, Implement, Evaluate. Both models emphasize a data-driven approach to modifying a process including research into best practices of other organizations. The DMAIC model emphasizes control of processes and data are collected in the second step. The ADDIE model emphasizes design of changes and data are not collected until the end of the process. However, neither model acronym emphasizes the iterative nature of CPI activities and the continuous collection of data and introspection about the improvement process itself. For this implementation of CPI, both data collection every semester and developing process changes between semesters are important. Examining the entire CPI process for relevancy of metrics and success is also critical to achieving CPI goals. This application of CPI began with Analysis and Metrics, the middle steps of both the DMAIC and ADDIE models. However, for the sake of clarity, this paper will report through the DMAIC model.

This application of CPI was motivated by a desire to prove the efficacy of a novel, 'grassroots' motivated mechanical engineering program to the industry and DoD organization partners supporting it. The novel program is the Antelope Valley Engineering Programs whose development and business model is documented elsewhere[8]. An understanding of the external customer (local industry) needs was developed systematically as part of another research effort[9]. That research highlighted the commodity nature of basic engineering skills, like dynamics, in that these skills are assumed to be acceptable in graduates of ABET accredited engineering programs without further development. Instituting CPI on the educational process of the Dynamics class will accomplish four things simultaneously: 1) improve the pedagogy in, thereby improving achievement of learning outcomes, in this dynamics class, 2) win the support of local industry, 3) satisfy ABET continuous improvement criteria, and 4) create educational efficiency in the novel program.

The necessity for a systematic and thorough approach to both developing pedagogical improvements and classroom procedures in the broadcast environment became evident during the first two semesters of this class. The Spring 2005 and Fall 2005 offerings of Engineering Mechanics: Dynamics illustrated the need for metrics beyond grades and course evaluations. For these semesters, only enrollment and grade metrics are available. Course evaluations were not conducted in those semesters and the only feedback the instructor received was by way the department chair relating complaints about the quality of the broadcast and feelings of isolation from the students. The grade distributions for the four semesters from Spring 05 to Fall 07 are shown in Figure 1 with class average grade and number of students enrolled in the legend. The distribution is mostly Gaussian, as expected for grading on a curve, but also shows large tails to the low end. As much as one third of the class earned a grade lower than 50%. The seemly large percentage of students with low grades and the desire to take control of the variables effecting student satisfaction motivated the application of CPI to this class.

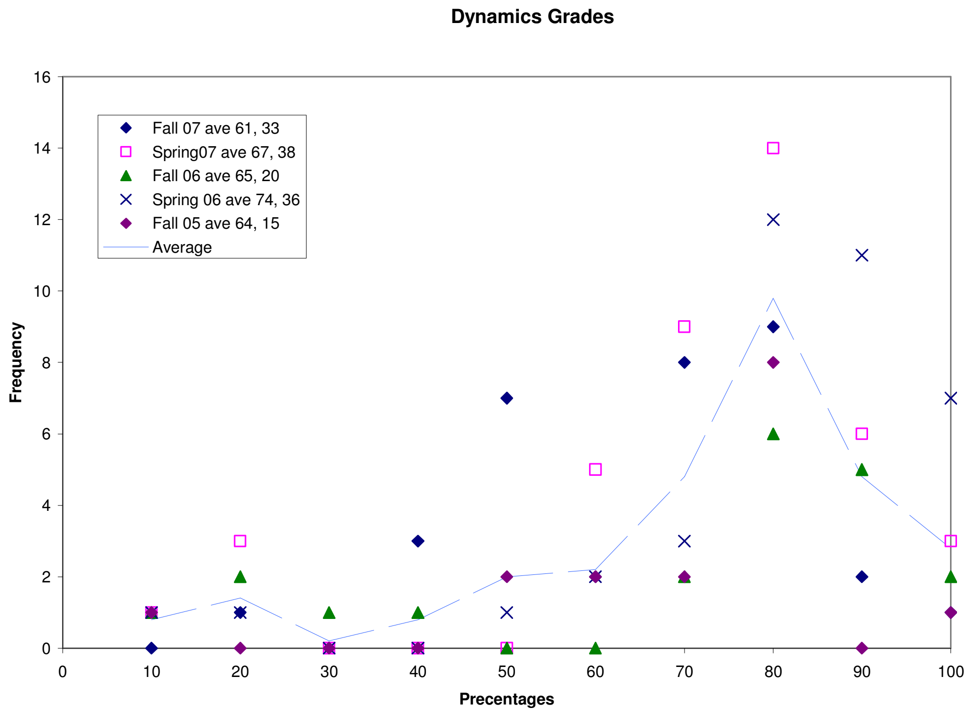

Figure 1: Weighted Final Semester Grade Distribution Over Five Semesters

Define

Because processes that create a product are often interrelated, it is necessary to first define and establish the boundaries of a process targeted for improvement, arbitrarily when necessary. In this case, no arbitrary boundaries need be established. This case is a junior-level Engineering Dynamics class whose physical boundaries encompass 245 miles of the grapevine in California. The class is generated at the remote learning site and is televised by interactive broadcast into the main campus to a room dedicated to, and in the building with, the other mechanical engineering courses. Its boundaries are well-defined in time by the beginning and end of a 16 week semester; and well-defined in content by pre-requisite and follow-on classes, ABET standards, and the material covered on the Fundamentals of Engineering examination[10]. The process begins with students who have completed pre-requisite mechanical physics, calculus, and statics classes. The purpose of this class is to develop critical fundamental engineering knowledge about unbalanced forces and the motions they cause. Problem solving discipline and mathematical modeling ability are developed. The process ends with a comprehensive final examination at the end of the semester. The instructional process itself is a heritage lecture style delivered through interactive broadcast. Homework is closed-form solution-style problems from the textbook for which the answers are given in the book. Problem recitation is built into class lecture. There is no accompanying laboratory, either physical or simulated. Examination questions are mixed conceptual and calculation-style with only about 20% of points from conceptual problems. (Conceptual problems require written answers, not calculated solutions.)

The Dynamics course instructional process is in control by design of the university environment. Material required to be covered is consistent over time by both ABET criteria and expectations of following classes, such as Machine Design and Vibrations. Prerequisite requirements ensure reasonable consistency of students entering the class. Pedagogy, classroom discipline, and assessment are under the direct control of the instructor. However, there are some variables affecting the process that are not under the direct control of the instructor or the department. The quality and consistency of the broadcast signal and support of proctors in the distant classroom are controlled by the computational support staff, a College, not a department-level, resource. The availability of graders and tutors are not under the control of the instructor. Textbook selection is conducted by consensus among the instructors teaching both statics and dynamics in two different departments. The University environment outside of the classroom is not under the direct control of the instructor. One of the goals of implementing CPI is to employ those factors under the direct control of the instructor to make the instructional process robust to variation in the factors not under the direct control of the instructor.

Measure

In the ADDIE model, measuring is usually considered as part of the evaluation activities, the last step. It is an independent category of activity as the second step in the DMAIC model. For this practitioner, measuring is a continuous activity that is frequently accessed. Both models depend on *objective* metrics which accurately reflect the state of the defined process at any time. For this particular class, several sets of metrics are available readily, only some of which are useful for CPI.

Course enrollment and student grades at course completion are inherent in the conduct of the class. If Dynamics were an elective class, enrollment might indicate changes in course or instructor popularity. However, because Dynamics is required for all mechanical and civil engineering majors, enrollment should reflect the health of the engineering programs in general. Course grades are based on calculation-style questions that require the ability to model a written problem statement analytically and to apply appropriate principles from physics. Therefore, preparation in calculus and physics influence course grades. Problem solution style is a controlled rather than measured variable. One style of solution is recommended in the text and that recommended style is used as a grading rubric for the homework and exam problems. The final course letter grades for each student are generated on a curve, whereas the raw weighted grades are not. Because of the curve, course letter grades measure the consistency of examinations and graded assessments over time. However, since examination questions change every semester, raw weighted grades may not be consistent over time.

College of Engineering standardized course evaluations provide insight into student opinions of instructor effectiveness. However, they are not designed to discern differences between interactive-broadcast and direct-contact instruction, nor assimilation of course content. These evaluations are commonly interpreted by faculty as "popularity reports" since they ask students to rank one professor's instruction style against that of other professors in the department. Because they are significantly influenced by the perceptions of the broadcast environment and are not a direct measure of pedagogical effectiveness, standardized course evaluations have limited value as a CPI metric. However, examining student comments may elicit information on student perceptions and suggestions for improvement. And, changes in course evaluation responses over time may indicate changes in student perception of either the instructor or the broadcast environment.

An objective measure of dynamics content knowledge is needed, separate from calculation-style exam grades, to generate data on changes in student content knowledge caused by course pedagogy. To generate these data, the Dynamics Concepts Inventory, DCI, was used as a pre- and post-course assessment of student knowledge. The Dynamics Concepts Inventory is a 29 question, standardized, multiple choice, first-principles assessment of student understanding of unbalanced forces and the motion they cause. The 29 questions in the inventory cover 11 fundamental concepts of force application, angular, and linear motion. The instrument was validated by focus group and beta testing. No calculations are required and detractor answers for every question indicate common misconceptions about forces and motion. Five choices of answer for each question are given with one correct choice; and "all of the above" and "none of the above" are not available answers. The Inventory is available through Dr Gary Gray at Penn State, or through the Dynamics Concepts Inventory Website: http://www.esm.psu.edu/dci/ or the Foundation Coalition Website: www.foundationcoalition.org/home/keycomponents /**concept**/**dynamics**.html. The DCI does not require calculations and does not test the ability to formulate mathematical models.

To assess student opinion of specific aspects of each semester's class, the instructor developed an end-of-semester questionnaire. Although the questionnaire was reviewed by a learning expert and a faculty member at a different university to remove bias and determine appropriateness of the questions, a focus group of students was not employed to validate the questionnaire. To incentivize students to respond to the questionnaire, extra credit points are offered for completion. Analysis of the survey responses is not conducted until after final grades are submitted for the semester. The survey consists of between 13 and 20 questions. Approximately 10% to 30% of the questions on the instrument changed each semester to reflect the exact circumstances of that semester's class. Questions on the survey probed the student reaction to the broadcast technology itself: "The quality of the DL signal did NOT interfere with my ability to learn the material in this course," and "the quality of the broadcast signal was good," interaction with the instructor: "I liked the virtual office hours in the Blackboard chat room," "emailing my instructor with questions was frustrating for me," and course pedagogy: "doing homework in groups helped me learn the material." With the exception of one question asking specifically which information students found most useful on the class Blackboard website, responses were five point Likert scale with a sixth option of not applicable. The questionnaire was administered online through Blackboard the final week of classes for the semester. In Fall 08, several open ended questions addressed what students liked best, liked least and what the instructor could specifically do to improve were added to the questionnaire in hopes of eliciting more actionable responses and greater student involvement.

Analyze

Figure 2 shows the enrollment in this Dynamics class from Fall 05 to Fall 09. The typical enrollment fluctuation between spring and fall is evident with spring semesters averaging 33.8 students and fall semesters averaging only 21.2 students. Although fall is the scheduled semester for mechanical engineering students to take Dynamics, this section is more heavily enrolled in spring, when fewer sections are offered. It is assumed that enrollment is lower in fall when students on the main campus have more options to enroll in direct-contact sections. However, the fall semester class starts at 9:30 a.m., but the spring semester class starts at 11 a.m. Therefore, differences in enrollment may also indicate a preference of the students for later class start times.

When students are informed of the broadcast delivery mode, enrollment in the distant section drops. In Fall 09, students were informed of broadcast delivery mode by e-mail the week before the semester began. Enrollment decreased by over 50% from the week before the e-mail was distributed until the class roster was finalized three weeks later. A seemingly large number of distant students drop the broadcast section within the drop-add period of the first two weeks of the semester every semester. Some students contact the instructor requesting information about the broadcast process before dropping the distant section. However, the Fall 09 semester was the only semester for which a datum was collected. This statistic shows the dislike and mistrust students have for broadcast delivery mode although there is no demonstrated difference in achievement of learning outcomes or course grades, as noted by Russell in "The No Significant Difference Phenomenon"[11] and by this instructor[12].

Student population in the mechanical engineering major remained relatively consistent over the period of this study while civil engineering enrollment grew by over 25%. Recognizing some growth in student population over four years may indicate a downward trend in the distant section enrollment starting in the Spring 08 semester. A new professor with a specialty in vibrations joined the faculty and began teaching Dynamics during this time. With additional faculty teaching dynamics, students wishing to drop the broadcast section had a more consistent option of enrolling in another, direct contact, section. For the CPI process, tracking enrollment reflects the relatively stable enrollment in the programs and that external or uncontrolled influences do not appear to be unduly affecting the process.

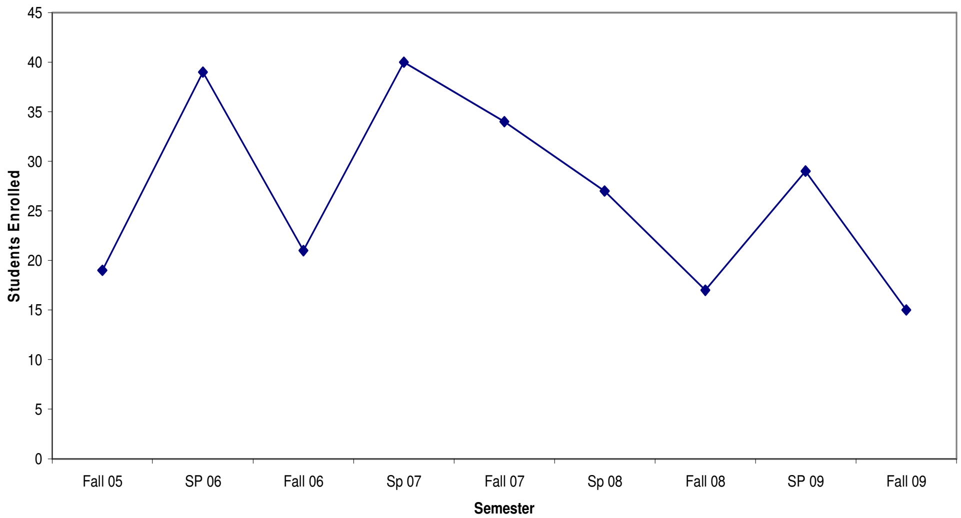

Figure 2: Dynamics Class Enrollment Over Nine Semesters

Average course grades are shown in Figure 3 with the grade distributions shown previously in Figure 1. The course is generally graded on a curve, so percentages of high and low grades should remain fairly consistent over time with an expectation that approximately 9% of students receive grades of "A." The grade statistics show that, on average, nearly 12% of students received "A" grades while 21.5% need to repeat the class with grades of D or lower. Figure 1 shows a distribution that peaks at the "C" grade category, as expected for a curve centered on middle "C." The average grade earned in the class is fairly consistent at 66.4% with a standard deviation of 5.6. Spring semester grades, semesters with generally higher enrollments, also tend to have higher average grades, 68.7% to the fall semester's 65.0%. However, these grade differences are within the standard deviation and are, therefore, not significant. No statistical difference between the direct-contact and distance student grade averages has been observed. The general consistency of the grades tends to indicate that the assessment, grading, and curving sub-processes are in control for this class.

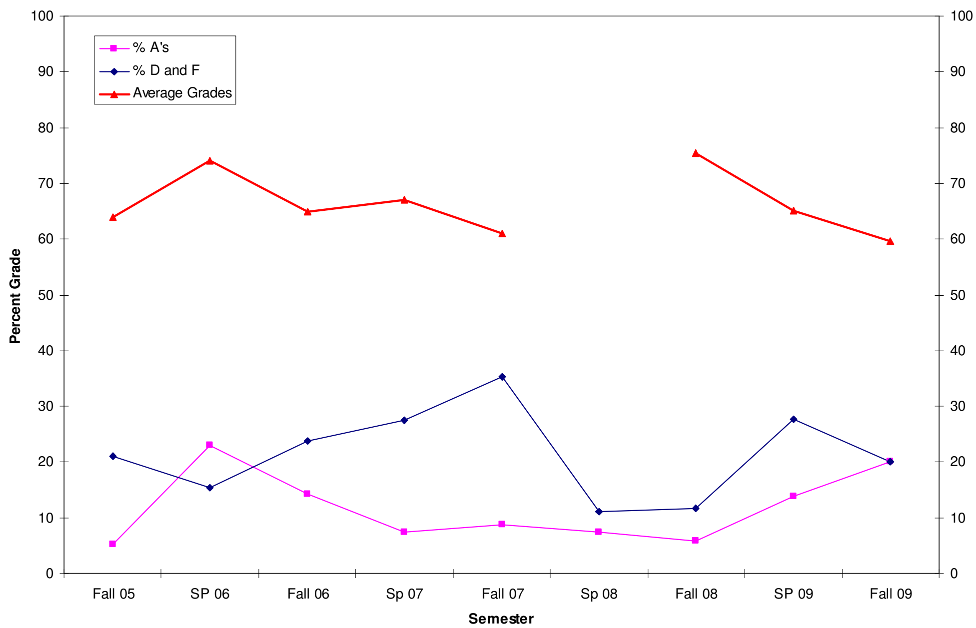

Figure 3: Average grades, Percentage of "A" grades, and Repeating Grades Over Nine Semesters

Standardized course evaluations were administered inconsistently over the period covered by CPI. Only two sets of evaluation results are known. For the Fall 06 semester for which course evaluation data are available, the two direct contact students both rated the instructor as well above average whereas 13 of the 20 main-campus (distant) students rated the instructor well below average. Because all of the direct-content students are non-traditional, take this particular instructor for multiple classes, and have this class as their only direct-contact lecture style class, it is impossible to discern if the student attitudes assessed by standard course evaluations are due to technology of the broadcast environment, student prejudice toward interactive broadcast, familiarity of the direct contact students with this instructor, or the pedagogy of this instructor. The partial results for the Fall 08 semester register specific complaints from distant students about the broadcast system, time required to correct signal quality issues during class, and extra example problems running over class time. The nature of these comments implies that the evaluation results are strongly influenced by broadcast quality rather than pedagogy. However, changes in this instructor's rating, or if the direct-contact and distant students ratings have converged, is not known. The large disparity between the responses of the direct-contact and distant students may be a symptom of the students' aforementioned dislike of the broadcast delivery method. The lack of data limits the value of course evaluations as a CPI metric.

The effects that changes made to course structure, organization of content, delivery technology, and classroom procedures had on student understanding of dynamics concepts is evident in the Dynamics Concepts Inventory scores shown in Figure 4. The class average scores from the pre-course Inventory of 7.5 agree generally with what is to be expected from the 9.3 value reported by Gray, at al.[13]. However, with an overall average score of eight correct responses to the 29 questions and a standard deviation in responses of 4.3, these average scores are not significantly outside the range of results expected for random guessing of 5.8 correct responses. No difference has been noted in DCI scores between the distant and direct-contact students.

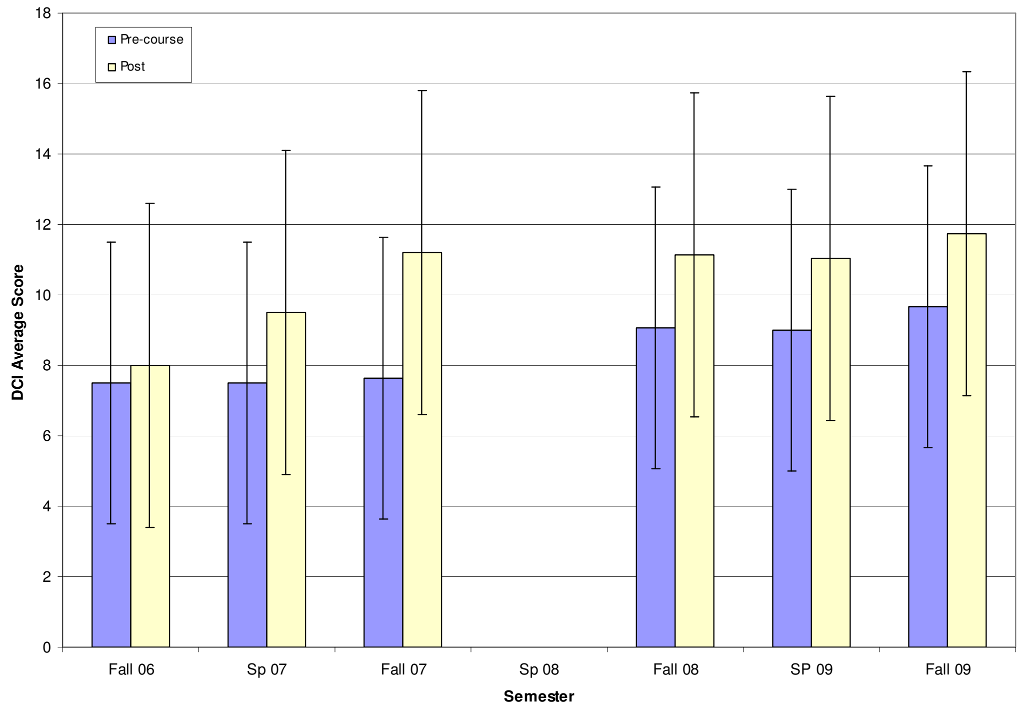

Figure 4: Dynamics Concepts Inventory Results Over Seven Semesters

The average post-instruction DCI score improved by almost 1.5 correct responses per semester for each of the two semesters ending in Fall 07. However, the average score gained only two points total for the four semesters from Spring 06 to Fall 09. The pre-instruction DCI scores also improved from 7.5 for the first three semesters to 9.2, causing the student achievement improvement caused by instruction to drop from a high of 3.5 points in Fall 07 to 2.0 correct answers in Fall 09. Students appear to be entering the Dynamics class better prepared than previously. These differences are also within one standard deviation and do not indicate actionable trends for continuous process improvement. However, these results indicate that efforts made to create a more satisfying classroom environment for students have done little to improve their understanding of dynamics concepts. The fact that average post-instruction scores have not risen above 34% on this standardized assessment for either direct-contact or distant students indicates that significantly different instructional techniques must be employed to improve content assimilation in Dynamics.

Potential causes for the lack of improvement in DCI scores are evident in the Foundation Coalition literature[14] and the Foundationalist movement generated by the physics instructional community[15] nearly two decades ago. This growing body of literature explains that is it the lecture method of delivery, rather than any individual instructor's presentation style that causes a lack of student achievement. The lecture style is fundamentally a student-passive content delivery technique. For learning to occur, students must be actively engaged in the pursuit of knowledge[16]. Anecdotal evidence supports the foundationalist framework for pedagogical improvement as well. One of the professors teaching physics at the community college that feeds the remote learning site upper division program uses Socratic and inquiry-based methods in developing learning outcomes, as published in reference 15. None of the 12 students known to have been taught through these methods who have matriculated from this particular community college[17] have earned less than a "C" in this dynamics course and a distinct improvement in student articulation of conceptual knowledge and critical thinking skills was noted when the first of these inquiry-based students arrived in this dynamics class. The inquiry-based body of literature, benchmark classes at other institutions, and best practices will frame the improvement design and development in the next CPI iteration.

For this course, final DCI scores correlate with final grades with correlation coefficients that vary by semester between 0.43 and 0.81. The data for the three most recent semesters is graphed in Figure 6. The overall correlation for these three semesters in total is only 0.34, indicating that the correlation of DCI scores to grades holds within a particular class but not as strongly from one semester to the next, as expected for curved grades. This correlation makes the DCI score an important metric for continuous process improvement. It indicates that grades are not subjectively assigned in this class. Tracking not only the DCI scores, but also their correlation with grades indicates the influence of analytical capability and problem solving discipline on course grades. The correlation between grades and DCI scores also implies that the desire to achieve a more uniform product – having more students pass the dynamics class – is possible by generally improving DCI scores.

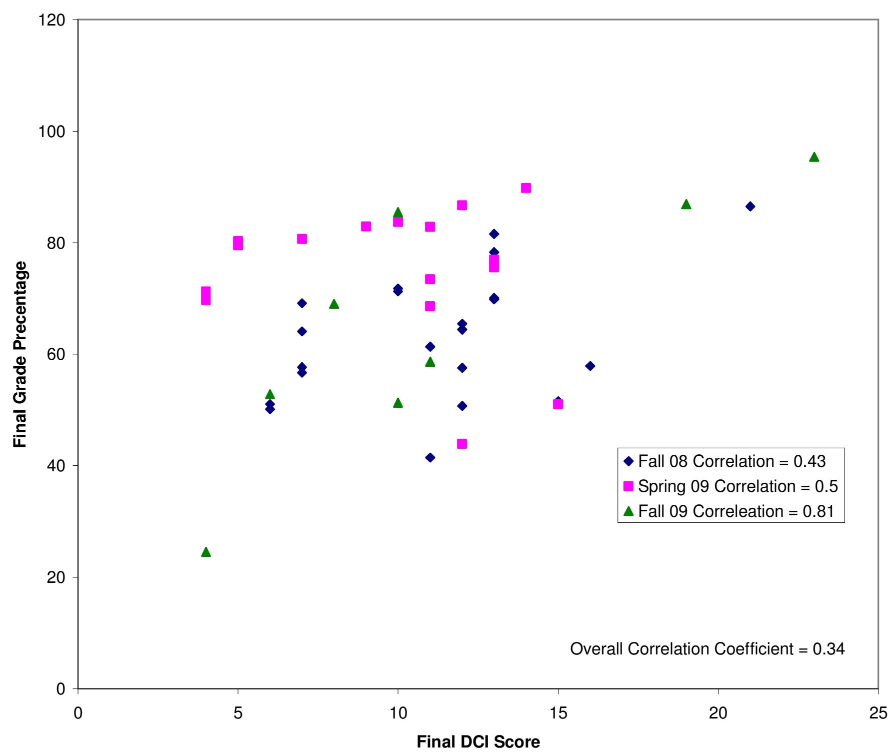

Figure 6: Correlation between Final DCI Scores and Grades

To probe student acceptance of the broadcast technology, the end-of-semester questionnaire asked: "The quality of the DL signal did NOT interfere with my ability to learn the material in this course." Figure 7 shows the percentage of respondents disagreeing with that statement, indicating dissatisfaction with the quality of the broadcast images. The quality of the broadcast signal is NOT in control. The 43% dissatisfaction statistic in Spring 06 motivated changes in the broadcast system so that the content image was broadcast in high resolution and a second screen was added to the room so the instructor camera image displayed continuously during class. Student dissatisfaction with the quality of the broadcast signal dropped to a low of under 17% in Fall of 07. However, the improvements have not been maintained with the content (instructor-written notes) reverting to low resolution in more recent semesters. Inconsistency appears to be more frustrating to students than a consistently poor image with dissatisfaction increasing from 54% for the semester in which the content image was only shown in low resolution to 66% for the most recent semester in which the content image was occasionally, but not always, broadcast in high resolution.

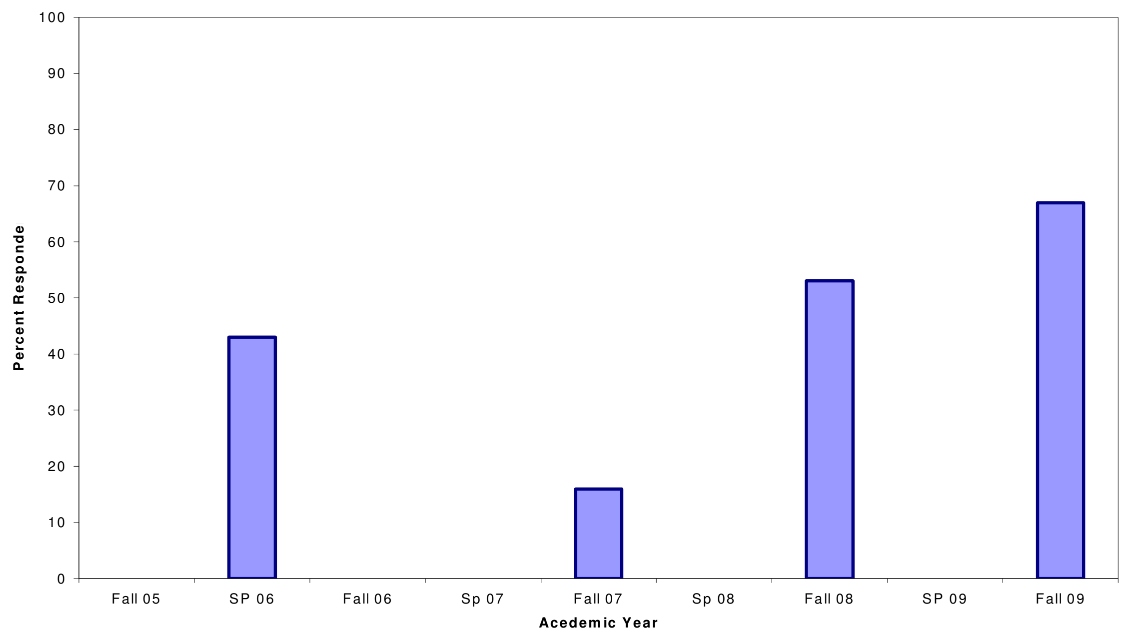

Figure 7: Student Dissatisfaction with Broadcast Quality by Semester

Questions regarding quality of contact with the instructor indicate that students appreciate contact with the instructor. Methods of providing out-of-class contact with the instructor have varied over time. E-mail has been consistently employed. However, student participation in e-mail has varied from less than 10% in early semesters to almost 30% with the most recent offering. No questionnaire questions directly address why students do, or do not e-mail the instructor. Only twice in nine semesters have students called the instructor on the telephone, although this contact option has also existed and been encouraged. There is apparently a strong student prejudice against telephoning an instructor; however, no questionnaire questions have probed this apparent prejudice.

Broadcast "office hours," VOIP teleconferences through Blackboard and other software, instant text messaging, and Blackboard chatrooms and bulletin boards have been attempted with little or no student participation. Chatroom, instant message, and bulletin board participation appears to be limited to those students who are already comfortable with these methods of communication, as indicated in the discussions by the students using those methods. The importance of student-initiated communication with the instructor to student satisfaction is not understood.

No questionnaire question directly addressed timeliness of instructor feedback through homework. However, when homework was graded and returned promptly, responses to questions about instructor interactions were generally more positive than when it was not. Problems with graders handling homework and delays in transmission of homework for grading frustrated both the instructor and students, and devalued the importance of this learning opportunity. In the one semester for which a grader handled the distant student's homework using a rubric created by the instructor, homework grading was inconsistent and graded work was delayed by nearly five weeks out of 16. Before the Fall 08 semester, a dedicated room assistant collected homework and hand written assignments from the distant students, then scanned them to the instructor as PDF files on a protected FTP server. This handling procedure allowed the instructor to control the grading of homework and any associated delay in returning graded work. However, in Fall 08 the collection and scanning service reverted to the college technical staff and delay in homework transmittal for grading frequently approached one week. In general, the homework handling sub-processes are not in control for this class. The next iteration of CPI metrics needs to collect information on how homework affects both learning and student satisfaction.

Improve

The first set of improvements was implemented in Fall 06 with introduction of the Dynamics Concepts Inventory and end-of-class questionnaire to gather data. The first problem identified through the CPI introspection and iteration process was the paucity of data that accurately and objectively reflected the state of the Dynamics instructional process.

A second CPI cycle ended with the Fall 07 semester. The focus during these three semesters was on improving the quality of broadcast signal and homework handling procedures. Broadcast signal was improved by the support technician by splitting the broadcast signal into low and high resolution components and having the high resolution image of the content screen projected to the large screen at the front of the room. A second smaller monitor was added to the front of the classroom that continuously broadcast the instructor camera view. During this time, a dedicated student assistant collected and scanned homework and other material for grading, proctored quizzes and exams, returned homework originals, and distributed materials to the students. The room assistant had no responsibility for grading. However, the assistant also provided a secondary conduit of information between the students and the instructor. Relevant "hallway grumbling" of the students, evidence of unethical conduct among the students, and frustrations of the instructor could pass between the students and the instructor in a casual and anonymous manner through the room assistant. The result of this improvement cycle was the decrease in student dissatisfaction to the lowest level as determined by questionnaire responses and establishment of a satisfactory set of homework handling procedures. However, many of these improvements were not maintained.

The third cycle began with the Spring 08 offering of Dynamics and focused on pedagogical changes in an attempt to improve final DCI scores, assuming that the signal quality and homework handling improvements would be maintained. All of the pedagogical changes implemented have been incremental improvements to the lecture method of instruction. Although many of these changes have been well-received, based on casual comments made by students in class and specific questionnaire responses, none have lead to significant improvements in DCI scores.

Addressing student concerns about the broadcast method of delivery directly by discussing literature, the “The No Significant Difference Phenomenon” (reference 11), and grade results from previous semesters early in the class may be comforting to students. But, it does not help them maintain classroom discipline throughout the semester. Similarly, an orientation to the importance of the study of dynamics over the four millennia beginning with Hammurabi’s code and ending with contemporary engineering failures caused by dynamic conditions from recent newspaper articles may address the ABET program outcomes f (ethical responsibility), h (societal context), and j (contemporary issues)[18], but does not engage students to apply the appropriate physics to stated problems. Introducing “communication practices” in the form of short take-home quizzes in which students were asked to describe a mechanical illustration were intended to foster e-mail interaction between the students and the instructor, but instead hinted that critical thinking about physics may be more of a problem for some students than problem-solution techniques. No additional data have been generated to further elucidate this supposition. Intervention of students poorly prepared in math required the development of a basic math quiz that tested students’ ability to integrate, differentiate using chain rule, interpret trigonometry problems, and understand geometry and related rates word problems. Experiences with this intervention indicated that, to be effective in modifying student behavior, interventions must be intrusive and carry appropriate grade points.

In-class demonstrations by the instructor are greatly appreciated by the students. Gears, tracks and pulleys, paper airplanes, and a large number of children’s toys can be used to illustrate physical principles in ways students readily comprehend and appreciate. Many of these demonstrations have been discussed in previous ASEE sessions[19]. Ranking Tasks[20], adopted from the physics community and used as a supplement to standard analytical modeling style homework, provide both critical thinking practice and a synthesis activity. These tasks challenged most students and provided not only a method of exploring individual physical relationships and definitions of terms, but also created a framework for comparing and contrasting different relationships like work-energy and impulse-momentum. These tasks challenged even the “best” students in class while the lowest scoring students comprehended and gained benefit from the practice. However, because these tasks were used to support homework, not as a basis for class discussion, full benefit of the Ranking Tasks might not have been achieved. Rearranging the order of presentation of the material in-class from its order in the text allowed greater concentration on the different relationships used to solve problems. However, it frustrated students with 50% of students responding to the questionnaire that they preferred the book order to the presented order.

Improvements made in the dynamics class pedagogy until the Fall 09 semester were evolutionary, rather than revolutionary, and did not result in significant improvements in DCI scores. The instructor progressed from being a novice to becoming a "fun" professor[21] with an engaging lecture style who is commended by students for flexibility in content delivery. However, although the students appear to appreciate this particular professor more in the most recent semester than in the first semesters teaching, the relatively high percentage of students earning grades of "D" or lower is persistent. DCI scores that judge fundamental understanding of the effects of unbalanced forces continue to be low. Metrics indicate that sub-processes thought to have been improved are not actually under control.

The Continuous Process Improvement discipline indicates that the defined process of a junior level dynamics class has not been improved and is not completely controlled, even though instructor confidence has improved and the instructor is now regarded by peers as "experienced". The CPI results directly contradict the instructor's personal feelings of satisfaction with the ability to deliver content, explain concepts, and assess learning outcomes. A lack of complaints to the department chair and the use of questionnaire results to discuss student satisfaction with fellow faculty have created the perception among the faculty that this instructor is proactive and an accomplished lecturer. However, being an accomplished lecturer has not improved DCI scores, just as the Foundation Coalition literature intimates. The data indicate that, that in spite of significant instructor confidence with the lecture method and content, significant changes in pedagogy are necessary to improve student understanding of dynamics concepts and student satisfaction.

Control

This application of CPI demonstrates the importance of controlling factors affecting a process. Improvements made to the broadcast system and homework handling procedures were not institutionalized. So, problems that frustrate students with the broadcast environment must be solved again. Because some resources are not under the direct control of the instructor and are not appropriate to be brought under the control of the instructor (the support technician), the next CPI iteration should attempt to remove reliance on these resources from the dynamics class instructional process.

Conclusions

Three major conclusions result from this study. First, Continuous Process Improvement can be applied to the academic environment. Second, the interactive broadcast process of this dynamics class is not in control. The lack of control is primarily affecting student satisfaction. Third, significant pedagogical changes are necessary to improve learning outcomes for this class.

Adopting the CPI methodology to improve delivery of course content and creation of learning outcomes has provided the objectivity necessary to motivate a fundamental change in pedagogy from student-passive to student-active techniques. Data analysis has created the understanding that although the broadcast environment influences student satisfaction, undue concern over it is a distraction from the pedagogical changes necessary to improve DCI scores and content understanding. Understanding the metrics and correlation between the DCI and grade metrics has highlighted a potential path for improving student learning outcomes.

The homework handling and broadcast environment must be controlled to improve student customer satisfaction, or the instructional process must be made robust to variation in signal quality and homework handling procedures. Several possibilities exist for controlling these classroom activities. One suggestion is to have the instructor physically in the classroom with the main campus students. This suggestion is not possible under the current realities of the remote program educational model and would remove the only in-person instructor from the remote classroom. Another suggestion is to make the homework handling procedures a student responsibility for heritage-style hand-written homework. Implementing this possibility will require action by the department or College to put a scanner in one of the student computer laboratories so students can scan their own homework and e-mail it to the instructor. Procedures governing student use of the scanner will then also need to be put into place. Implementing these procedures may result in an effective, if somewhat cumbersome homework sub-process. Changing the nature of the homework so it can be completed electronically without evidence of hand calculations, is also a possibility. However, implementing a change of homework style will require research into the effectiveness of non-traditional homework activities as well as curriculum design and development. No data have been collected in this study on the efficacy of heritage-style homework in the instructional process. Examining the role of homework in developing learning outcomes may provide benefit in improving DCI scores, eliminating wasted effort from the learning process, and improving satisfaction.

Online delivery, whether synchronous or asynchronous, would change the responsible party for broadcast quality from college-resource personnel to the student, instructor, and a university-level support group. A larger support system with a stronger mandate to ensure content delivery quality might improve signal quality and consistency of signal; thereby improving student satisfaction with the delivery environment. A testing center on campus offers support services, like proctoring, for hybridizing the assessment portion of online classes. Publicizing the course as an online or hybrid section would allow students to self-select instruction according to their desire for physical “face time” with the instructor. Students knowingly and willingly enrolling in an online section inherently accept a technological intermediary to student-instructor interactions. This tacit acceptance of alternative communication methods may improve student satisfaction with instructor interactions. Exploiting the “anonymity of the internet” may also make it possible to create a personally challenging, but comfortable, learning environment for students. Embedded simulations and “virtual laboratories” are also possible. Taking advantage of the process monitoring and content embedding options of content presentation tools like Blackboard may enable the development of student-customizable learning environments and content review mechanisms that would create individualized learning experiences for students. Recognizing the potential of exploiting technology as a tool for developing learning outcomes is a necessary paradigm change to improve access to learning as documented by Brown[22]. The potential for delivery improvement by developing the course for online or partially online delivery is significant. However, implementation will require significant pedagogical development.

Recognizing that a paradigm shift in pedagogical techniques is necessary implies the need of a defined curriculum development effort. A framework categorizing the activities of curriculum development has been forwarded by Tanner and Tanner[23]. Curriculum development conducted during the first CPI iteration was of the Imitative type, implementing syllabi developed by established professors which maintained the heritage lecture-style pedagogy. The second CPI iteration was not focused on pedagogy. The third CPI iteration saw curriculum development of the Meditative type. This type of development is concerned primarily with the micro-curriculum of an individual class, but modifies established pedagogy based on research-based best practices. The next iteration of the CPI process will require the adoption of several activities of a Generative-Creative curriculum development effort but will remain confined to the micro-curriculum level of the Dynamics class. Benchmarking, collaboration with experienced practitioners, and the generation of solutions to known problems will be necessary. However, the Foundationalist movement provides a student-active pedagogical framework to be benchmarked.

The Next Iteration

The mantra that good pedagogy is good pedagogy[24], regardless of delivery technique is supported by the analysis of metrics used in this Continuous Process Improvement application. Practices used to develop high-quality learning experiences are enumerated by Ragan[25] that include setting goals, scripting interactions, assessment, evaluating instruction media, and creating learner support mechanisms. The next iteration of CPI for this dynamics class requires significant purposeful curriculum development. A new implementation of dynamics content using student-active learning practices such as Socratic interaction, inquiry-based methods, and "virtual laboratories" is necessary. To control the quality of broadcast signal under the current delivery model, it is desired to develop this class for hybrid synchronous online or asynchronous on-line delivery. Non-value added activities educational processes need to be identified by consulting educational research literature. Ineffective homework and class activities can then be eliminated during course development. An appropriately designed survey instrument is needed to gather student satisfaction and pedagogical efficacy data to inform follow-on iterations of improvement. Changes to pedagogy, curriculum, and environment that are demonstrated to be successful need to be documented and institutionalized.

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