AC 2008-305: USING THE DEMING CYCLE FOR CONTINUOUS IMPROVEMENT IN ENGINEERING EDUCATION

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Using the Deming Cycle for Continuous Improvement in Engineering Education

Abstract

As engineering programs refine assessment plans based on ABET accreditation requirements, there are many lessons to be learned from the successes and failures of industrial quality improvement movements. In 1997 as we were developing new undergraduate engineering programs we chose to use the Deming Plan-Do-Check-Act cycle of continuous improvement as our model for program assessment. This paper reviews the assessment system we put in place for continuous improvement, results obtained over the last ten years, and challenges of maintaining a culture of continuous improvement.

Our model involves assessment and continuous improvement at four distinct levels. First, at the constituent level, we have a set of processes for evaluating how well we are identifying our constituents, listening to them, and responding to their inputs. Second, at the program level, our processes identify needs for new educational programs, determines the objectives of these programs and evaluates our success at achieving those outcomes. Over the last 10 years, these processes have resulted in the creation of four new programs and the phase out or modification of others. Third, at the curriculum level, we have processes to improve the curriculum to better achieve program objectives. We will describe how these processes have led to various corrective and preventative actions and the results of those actions. Finally, at the course level, we have processes to encourage annual improvements in individual courses and to obtain data from individual courses for use in the assessment of program educational outcomes. By linking these levels together we have been able to reduce the faculty workload involved in assessment activities while maintaining a high degree of faculty involvement.

Introduction

A wide variety of models have been proposed and used for assessing the quality of educational programs but much of this work has been performed independent of the large body of research regarding quality improvement in industrial settings[1]. While clearly the industrial and academic environments differ and each provides unique challenges for the implementation of quality improvement programs, we believe that much can be learned from the work of manufacturing quality experts such as Juran[2], Crosby[3], and Deming[4]. The fact that their work has produced clear, measurable results in many diverse industries has motivated our efforts to apply their methods to improving the quality of our graduate and undergraduate engineering programs at our university. In particular, we have adopted a Continual Improvement Process which employs Dr. W. Edwards Deming's Plan-Do-Check-Act model to encourage systematic quality improvement in multiple ways within our school.

The Deming cycle, shown in figure 1 and also known as the Shewart cycle, and the PDCA cycle, is a simple system to describe a continuous improvement cycle. While this cycle is simple, it is not easy. The four phases of the cycle are known as the plan, do, check, and act stages.

Plan

The planning stage of the traditional Deming cycle is the design of a change for the improvement of quality. In this stage one would identify the quality characteristics to be improved, possible methods for improvement, and measurement instruments and acceptance criteria for testing success. The primary challenges in this phase are correct identification of the change with the best opportunities for improvement. Wide scale buy-in from the employees due to previous successes is the best way to ensure that opportunities are identified. Examples from industry would include considering converting a manufacturing process to use a new machine tool with tighter tolerances, or a change in employee training to reduce errors.

Do

The second phase of the cycle is performing the experiment or implementing changes for the purpose of measuring the effects of the change on the quality of the product. While the tests performed during this phase are often small scale experiments, under some circumstances they are large scale tests of limited duration. In either case, it is critical that those involved understand that the primary purpose of the test is to gather data on the effectiveness of the proposed change. The biggest challenge in this phase is correct implementation of the experiments. Careful planning in the previous stage makes this easier to accomplish. In our earlier examples, this phase might consist of a pilot production run with the new machine or the training of a small cohort of employees using new methods.

Check

The third phase of the Deming cycle consists of measuring the results of the experiment and determining whether the resulting changes in quality were sufficient to justify large scale implementation of the change. The most common problem in this phase is obtaining inconclusive results. Good implementation of the experiments in the previous phase is the best way to assure success. In our examples, we might compare yields using the old and new manufacturing processes or error rates among employees receiving differing training.

Act

The fourth stage of the Deming cycle consists of the large-scale rollout of the change or the decision to maintain status-quo and try other experiments. In either case, the cycle returns to the planning stage as new improvements are considered. The primary challenge in this phase is obtaining employee buy-in to the changes. Conclusive data from the previous phase can simplify this problem. Our example cases might conclude with the purchase of new machines to roll out the new manufacturing process or retraining of employees using the new training methods.

As the reader can see, each phase in the process requires different skills, has different pitfalls, and depends on success in the previous phase. While the startup of such a process can be difficult, successes make future successes easier.

Initial implementation of this approach at our university was eased by the large fraction of the faculty with experience in industry. This core group had seen the success of the Deming model in practice and that evidence provided a starting place for the cycle. It is clearly our hope that our own efforts to apply the cycle to academic program development can provide a similar catalysis for other programs. However, an alternative way to start a Deming cycle is to start with small, course level improvements that do not require buy in from large numbers of faculty and use those small scale successes as a starting point for broader acceptance.

Multi-Level Continuous Improvement Process Model

While ABET (The Accreditation Board for Engineering and Technology) has described a two loop process for assessment and continuous improvement[5], we have found it useful to think about our continuous improvement process as containing four loops with different goals and timeframes. Each of these loops is envisioned as a Deming cycle as shown in figure 2. Our top level loop attempts to ensure that we have the right educational programs to accomplish our school's mission and to satisfy our various stakeholders. The second level loop ensures that successful completion of these programs results in the desired attributes in our graduates. The next level verifies that the program curriculum results in educational outcomes that lead to the desired graduates. The lowest level ensures that individual courses are successful in leading to success in program educational outcomes.

There are several advantages of this four loop model. First, by adding a clearly defined process control loop for identifying the need for new programs or the need for new program objectives, we are able to formalize and institutionalize external input to our program far more effectively than the more passive review process of the traditional external advisory board. Second, the inclusion of a separate loop for course development and improvement provides a clear opportunity for individual faculty members to obtain feedback on their courses, and demonstrate how improvements in their courses support program educational outcomes. Third, the discrete linkages between levels show clearly the connections between decisions made at higher levels and their implementations at lower levels or conversely, how decisions made at lower levels affect performance at higher levels. To see how these levels work individually and together, we shall first examine each level in detail, then how they interconnect.

Level 1 – Constituents

Our School of Engineering's mission is to produce well-rounded, innovative engineers and technology leaders who have the technical skills, passion and courage to make a difference. In order to translate this mission into educational programs we seek input from various constituents within and outside the university. Initial identification of opportunities come from multiple sources including parent, student, employer and alumni surveys, industry advisory board (IAB) and faculty recommendations and environmental scans. Through our ongoing strategic planning process, these mechanisms are regularly used and the results discussed at IAB and faculty meetings.

Potential new programs, or changes to the goals of existing programs, are considered in the light of several key strategic questions. First, have we correctly identified all of our constituents? It is often possible to overlook potential stakeholders (e.g. community partners for service learning) or to fail to notice when constituent groups have split into two or more groups with divergent interests (e.g. when graduate and undergraduate students have very different needs). New stakeholders can often be identified because of apparent contradictions in input from constituents. The second question is how well our current programs satisfy the current needs of stakeholders. The third question is whether our existing programs are sufficiently forward looking. Satisfaction of current stakeholder needs alone is not a good indicator that a program will continue to be successful. Because of the long time frames involved in substantial changes in educational programs it is necessary to anticipate changes in technology and changes in customer needs. Finally, we consider how well stakeholder needs are met by other regional programs. We believe in working cooperatively with other institutions for the benefit of our stakeholders and occasionally discover that the best solution for our stakeholders is to direct them to existing programs elsewhere.

Once the need for a new program is identified, a program advisory group is formed with internal and external members to develop a set of program objectives in accordance with ABET criteria[6]. These objectives are used by the second Deming cycle for evaluating the effectiveness of our program and are used in future iterations of the top cycle to determine if the program is still meeting the needs of the constituents. In the language of systems engineering, this top level cycle consists of the development of product specifications from customer requirements and the validation that the program meets those requirements. In the past 10 years, this process has resulted in the creation of four new programs and the discontinuation of one other program.

Level II – Program

Once program objectives exist for a new program, a curriculum must be developed to achieve those objectives. The second Deming cycle at our university consists in the development and refinement of the educational outcomes to ensure accomplishment of program objectives. We know from the study of complex systems[7,8] that systems with long time lags from process to measurement tend to be unstable and difficult to control. For this reason, in addition to measuring program objectives, we measure achievement of program outcomes at graduation and correlate those measures to accomplishment of program objectives.

Measurement of accomplishment of program objectives is done via several instruments. Since these objectives can only be measured once the graduates have been in the workplace for a few years, our primary measurement instruments are surveys of alumni and their employers. In addition to asking directly about how well our graduates have accomplished the program goals, we ask employers to comment on characteristics that differentiate our graduates from those of other schools and we then compare these characteristics to our objectives. As an additional assessment tool, we perform an analysis of alumni resumes, looking for promotions, patents, and published papers as evidence of technical accomplishments. Similarly, we use professional development and continuing education on the resume as indications of lifelong learning. Since our school also seeks to develop graduates who become an active part in their communities, we look at community involvement on the resume as indications of success in this objective.

Data from these various measurements are reported to the faculty at an annual assessment retreat and accumulated for formal analysis in a periodic program review. The program review teams include representatives of key stakeholders, including faculty, Industry Advisory Board (IAB), alumni, and other relevant industry and community representatives. These reviews serve two purposes, first evaluating how well our programs meet their objectives and secondly evaluating how well successful completion of our learning outcomes correlates with success of our graduates. In the first of these purposes they provide data for the topmost level of continuous improvement and in the second they provide data for the planning of changes in program outcomes.

Level III – Curriculum

Given a set of program educational outcomes, a curriculum is developed to achieve those outcomes. As part of this original curriculum development, a set of required courses is identified and for each of these courses a set of course learning objectives is specified. The course description and learning objectives are controlled by the curriculum committee while the details of course implementation and delivery are left to the discretion of the instructor. This minimizes the required administrative oversight for the class and maximizes initiative of the individual faculty members. Similarly, allowable sections of electives are identified based on alternative ways to accomplish the program outcomes. Measurement of the curriculum occurs annually at the assessment retreat where multiple independent measures of the program outcomes are presented and discussed. These measures include assessment of individual courses, assessment of student abilities during senior design by members of the faculty, IAB and local industrial sponsors, student self-assessment surveys, and nationally normed topical examinations. As a result of these annual assessment retreats a number of substantial changes have been made to existing programs. For example, in a recent assessment retreat student self-assessments and faculty observations of weak programming skills led to an interdepartmental project to remedy the situation.

Level IV – Course

Individual instructors are responsible for design, implementation, and delivery of courses that effectively and efficiently achieve the course's learning outcomes. Each semester, individual instructors assess the effectiveness of their courses for three purposes. First, an individual student's accomplishment of course learning outcomes is a key part of assigning student grades. Second, accomplishment of course learning outcomes is used as an assessment tool for assessing the curriculum. Third, assessment of how well students have accomplished the course learning outcomes is used to improve the course in future offerings. It is the use of course data in this last form as feedback for course improvement that is addressed in the fourth, course level, Deming cycle.

Since each instructor is responsible for assessment of course learning outcomes, various methods are used including portfolios, reflection papers, feedback from follow-on courses, pre and post tests or concept inventories, and grading systems that tie grades directly to accomplishment of outcomes[9,10,11,12]. The results of individual course assessments are analyzed by the instructor and reported annually in both an annual faculty report that is used for faculty evaluation and in a course evolution manual that documents the improvement of the course over time. Instructor assessment of courses is presented at the annual assessment retreat and is used cumulatively as one measure of accomplishment of program learning outcomes.

Interlevel Interactions

The complete set of four levels along with the interactions between them is shown in figure 3. It is easiest to understand the relationships between the levels by starting at the bottom, or course level. Given a set of course learning objectives provided by the levels above, our goal is to optimally achieve those objectives for all of our students. The planning phase of this Deming cycle will consist of developing or selecting lesson plans to accomplish and assessment techniques top measure student learning[13]. The “Do” phase is delivering the new or revised course. The “Check” phase is assessing student learning and evaluating the success of the course. Finally, the “Act” phase is the continuation of the new course or the decision to make future alterations to improve student outcomes.

While this cycle appears to stand on its own, the course learning objectives are produced in the “Plan” phase of the curriculum level loop and the course assessments provide data for “check” phase of the curriculum level loop. In short, the course level loop taken as a whole provides the “do” phase of the curriculum loop.

Similarly, the curriculum loop receives its goals in the form of program educational outcomes from the planning phase of the program level loop above and provides assessment of educational outcomes to the check phase of the program level loop. Each Deming loop in the system provides the “do” cycle for the loop above it and each loop provides the quality criteria for the level below it. In this way, it is easy for faculty, students, and other constituents to see the effect of changes as they propagate through the system.

Conclusions

By applying a well tested quality improvement technique to engineering education, we have been able to take advantage of a wealth of pre-existing knowledge in the development of our assessment processes. Recognizing the importance of faculty involvement in program assessment, we have developed an assessment program that ties the activities of individual faculty members in their courses to the accomplishment of program outcomes and objectives and the assessment of those outcomes and objectives. Finally, by creating a separate process for identifying new programs and changes in our environment we have institutionalized an external focus. Taken together, the four Deming cycles operating at the constituent, program, curriculum, and course levels tie internal and external stakeholders together for the continuous improvement of our engineering programs.

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Figures

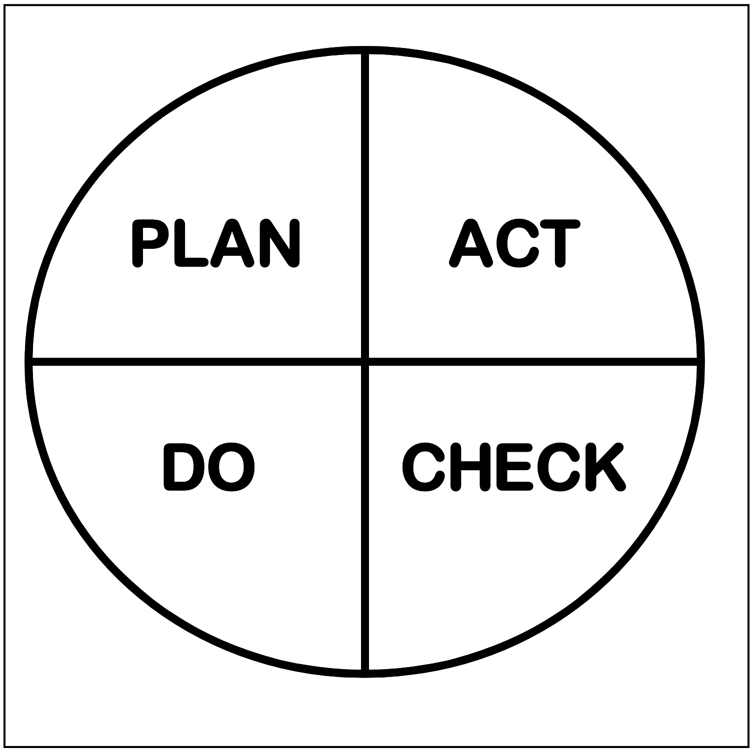

Figure 1. The Deming Cycle, also known as the PCDA cycle and called the Shewart cycle by Deming

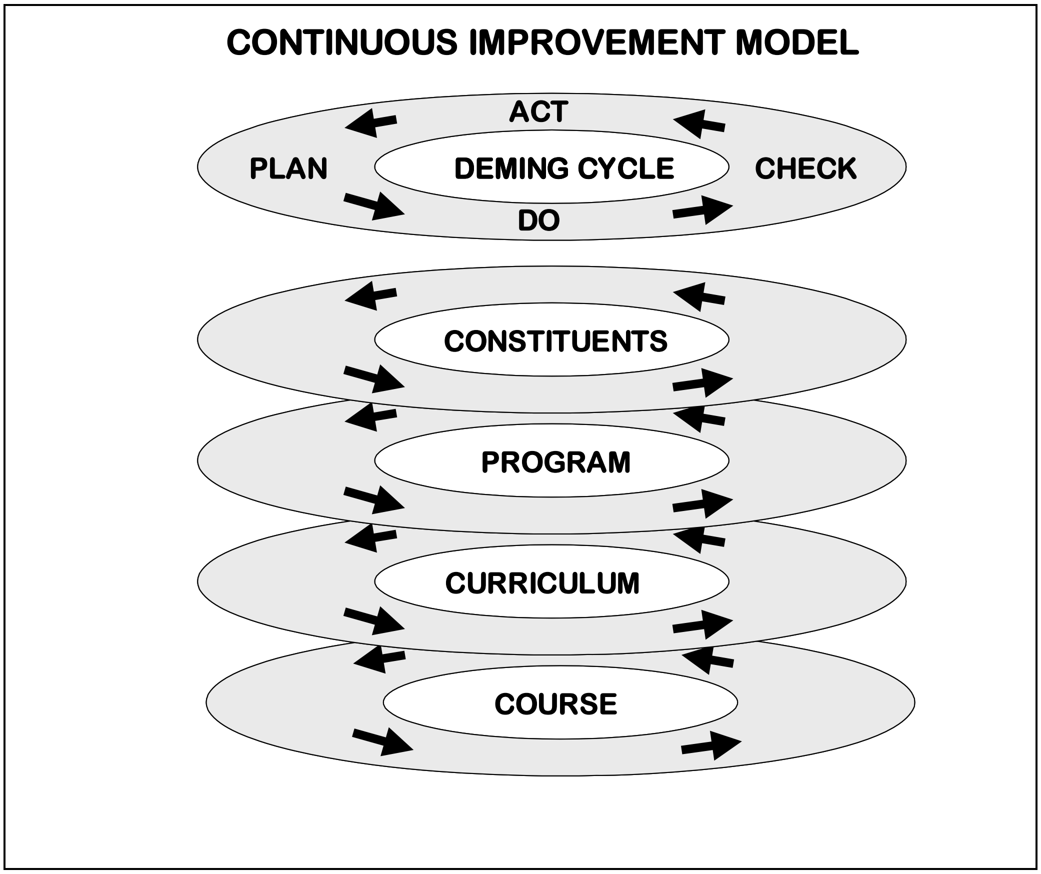

Figure 2. The Application of the Deming Cycle to Educational Program Development

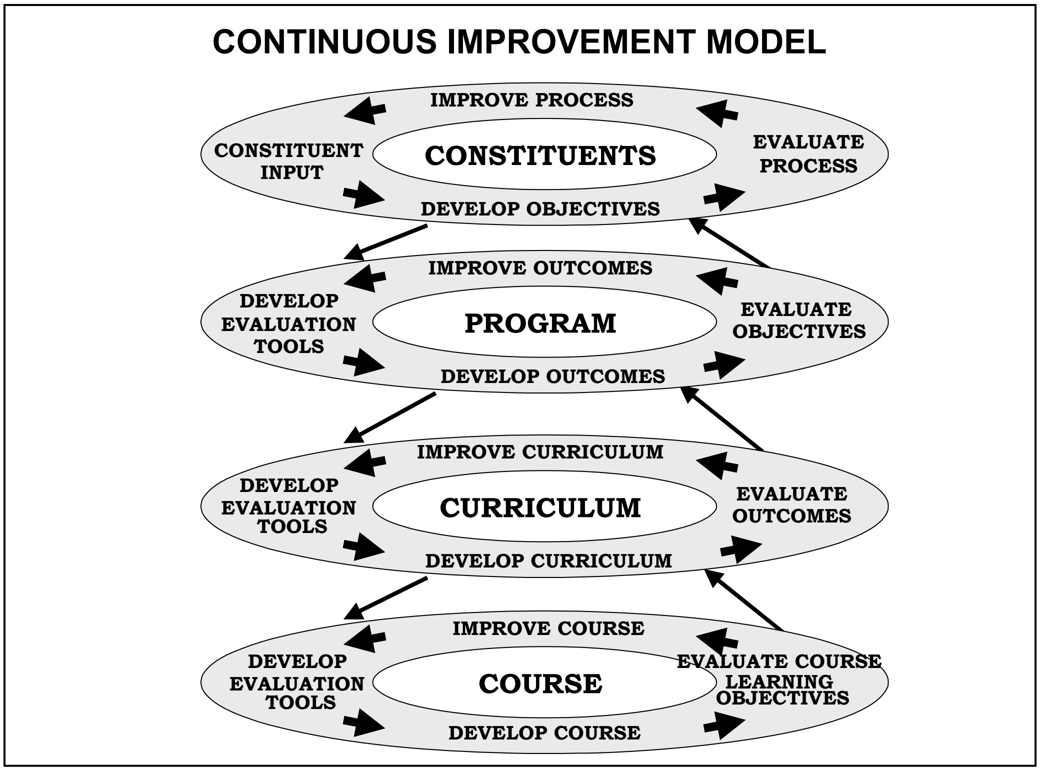

Figure 3. Details of the Four Level Deming Cycle Applied to Course, Curriculum, and Program Development