

Concurrent Engineering: A Partnership Approach

Robert P. Smith / Russell R. Barton, Craig A. Nowack / Jose L. Zayas-Castro
University of Washington / Penn State University / University of Puerto Rico Mayagüez

Introduction

There is an increasing focus on product development in engineering education. This change is a response to the need for engineering graduates to be able to provide immediate and tangible benefit to manufacturing companies in an era of heightened competitiveness. The focus on integrative product development aspects in the manufacturing process have been termed *concurrent* or *simultaneous engineering*, a focus which echoes long-standing themes in product development practices.^{1,12} Nevertheless, presenting these ideas in undergraduate engineering education calls for a departure from the usual content and pedagogical approaches.

The goal of this paper is to describe the development of a new course in concurrent engineering. Teaching concepts in product development benefits greatly from a hands-on approach. We have attempted to establish this goal in three ways: by developing and using a number of laboratories and demonstrations, by inviting speakers from industry who can make classroom lessons concrete, and by using cases as the basis for class discussion. This paper includes a discussion of the curriculum, of existing teaching materials, and of specific methods and materials developed for the course. The course was developed jointly by faculty and research assistants at the University of Washington (UW), the University of Puerto Rico's Mayagüez campus (UPRM), and at Penn State (PSU), as part of the *Manufacturing Engineering Education Partnership* (MEEP), funded through the ARPA Technology Reinvestment Program.⁸

Course Curriculum

Several important constraints affected the development of the curriculum. First, MEEP objectives call for a curriculum that is practice-based, using the *Learning Factory* (a hands-on design/prototyping/manufacturing laboratory) at each institution to provide hands-on activities. Second, the curriculum should stimulate team initiatives and interdisciplinary participation. Third, the curriculum should provide a comprehensive coverage of concurrent engineering topics. Finally, the curriculum must be flexible enough to meet the differing needs of the MEEP partner institutions. All three institutions share some common characteristics: class enrollment made up of a multidisciplinary group of electrical, industrial, and mechanical engineers, and local industrial support that has been active and enthusiastic. At the same time, some differences exist: the partner school's academic programs show different requirements, program lengths are different (four versus five years), and terms are different (quarters vs. semesters). In addition, the industrial sector has a different composition at each of the institutions.



As a consequence, we adopted a modular to allow flexibility. Modules have been developed for the following topic areas:

1. Concurrent engineering: definitions and philosophy
2. Teamwork
3. Including the voice of the customer
4. Interface of manufacturing and design: design for manufacturability
5. Project management
6. Other life cycle aspects
7. Product costing: activity based costing

Existing Teaching Materials

A comprehensive coverage of concurrent engineering requires a rich mix of both engineering concepts and managerial issues. We chose to use engineering-specific case studies to provide sufficient context and complexity to be realistic.

The existing textbooks in this area typically suffer from one of two shortcomings. Engineering-oriented books contain extensive discussion of the engineering design process, design-for-manufacturing, and often customer need identification, but do not discuss organizational and managerial issues in product development.^{3,9,15} On the other hand, textbooks from the management literature do not discuss many important engineering issues, such as the role of manufacturing processes on product design.^{11,17} In addition, most texts do not provide a hands-on, case based approach.

The book which most closely matches our coverage and our pedagogical approach is [6]. This text is used at UW. The first half of this text contains information about the important themes of concurrent engineering, while the second half illustrates those themes with a number of industrial cases. The shortcomings of this book include its age and in particular the age of the cases, most of which date from the mid-1980s. Also, because the cases are written by participants in the case design activities, they lack a critical and objective eye.

The best textbook for case-based teaching is [2]. These cases are rich, detailed and current. The problem with this text is its relative dearth of engineering information, which requires supplementary readings from more engineering-oriented texts. There are two books which contain good description of the tools and techniques of concurrent engineering.^{14,16} Neither of these books contains explicit cases. These books, along with [4] were used to supplement the Clark and Wheelwright text at PSU. At UPRM, class notes, developed using all of the above resources, were used in place of a formal text.

Two books cover some aspects of concurrent engineering at a level which is too advanced for an introductory class. One text has good and rigorous discussion of organizational effects of cross-functional work, but does not have enough emphasis on fundamental techniques such as DFA and QFD.¹³ The other advanced text describes a number of advanced computer applications, but lacks a broad coverage of concurrent engineering.¹⁰

Proposed Methods and Materials

In order to accomplish the goal of hands-on teaching, we examined methods for teaching engineering design practices. We focused on four areas: adoption of cases as a teaching method, the use of formal team



training, the role of laboratories in teaching product development concepts, and the use of outside speakers.

The use of cases as a teaching tool requires changes in student preparation, instructor preparation, and instructional facilities. The students must realize that it is they who are responsible for presenting the bulk of the material during the discussion, while the instructor acts as a moderator. For classroom discussion, it is useful to arrange the class room differently from the usual lecture configuration, with the instructor at the front and all other chairs trained on the blackboard. Instead, the chairs and tables are arranged in a circle so that students can speak with each other directly.

The team dynamics section of the course was particularly emphasized for the PSU course offering. It was placed in the beginning of the semester after two case discussions on the general aspects of concurrent engineering. This part of the course consisted of three sessions on team issues, two team building activity sessions and a demonstration session of electronic meeting software. The team issues included having clear goals, open communication, good leadership, trust, the ability to deal with diversity, and appraisal and reward systems in a company that uses project teams. Key references for this course segment included [5] and [7]. During this segment of the course, team building activities were conducted by facilitators from the Shaver's Creek Environmental Center. These activities were held on campus during the regular class meeting time. During these sessions, the class was split into groups of 15 students for outdoor group activities including a 'group juggle,' which the facilitators related to industrial situations that the students would be likely to experience.

Laboratories provide a key component of the hands-on experience in this course. These activities required significant time for preparation and supervision. We have developed labs for design-for-assembly analysis, customer need identification, and cross-functional team behavior. The use of speakers from industry to present concurrent engineering concepts has had significant benefit in course offerings at all three partner schools. Outside speakers add credibility to the concurrent engineering topics covered by the faculty. Our experience has been that many of those involved in concurrent engineering projects are willing to take time to speak to students.

Curriculum Development Process

The curriculum was developed by a team consisting of faculty from each partner institution. UW developed and first offered the course in the Spring of 1995. PSU and UPRM piloted the course in the Fall of 1995 using UW materials and experiences. A strong interaction was established among faculty and research/teaching assistants of the three institutions. A total of seven graduate assistants participated in the development of the course, using the Internet to exchange information. Learning Factory facilities at each institution have been used for practice based learning and teaching.

In the classroom the developmental process has been evolving. Initially the intent was to have team activities limited to the lab exercises. However, since teamwork plays such an important role in concurrent engineering, team activities were expanded to include in-class exercises and written assignments.

Student Experience and Assessment

The results to date show a high level of satisfaction at each institution. Students expressed a genuine interest and curiosity about concurrent engineering. Many were not sure what the term meant, but had heard about it through work experience, magazine articles, or job interviews. Many students had initial feelings of apprehension about the subject material and course expectations. It was not until the latter third of the course that students were able to formulate a clear definition in their own minds of concurrent engineering.



Because of the general feeling of apprehension, students tended to wait to be told what to do, and to be anxious about assignments. It was difficult for students to take initiative when faced with risk, especially for the in-class case discussions, which involved as many as thirty students.

An interesting side effect to the team building sessions at Penn State was a noticeable improvement in case discussions held during the class periods following the team building activities. The students were less apprehensive and more willing to volunteer their opinions. The result was a more dynamic discussion of case study issues. Unfortunately, these results did not last the entire semester. The remaining discussions were still healthy, but they lacked the edge gained from the team building activities.

Faculty/curriculum assessment has been through course evaluation questionnaires. At UPRM the lectures have been evaluated by the students as a feedback mechanism to insure continuous improvement. Overall, the students rated the course as a very interesting, but exhausting experience. Reasons for this feeling included the range of topics covered (too large), the readings (too extensive), and the projects (too fuzzy, too lengthy). Many students compare the amount of work to that of a capstone design course. Students enjoyed the laboratory activities at all institutions. In particular, the keyboard dissection lab was very effective for illustrating design-for-assembly issues and numerical methods for assessing alternate designs.

Student assessment has been through examinations, reports, presentations, labs and peer evaluation. At Penn State, students were evaluated in part based on participation in the case discussions, and on responses to specific questions on each case. Students were provided with the questions in advance, and had to come to class prepared to discuss them. For each case several students were selected at random to answer the questions and initiate the case discussion.

Future Activities and Summary

Overall, the course has been a success. Changes to the syllabus will be minor for next year's offerings. We would like to see the students applying the principles they learn in this course to senior design project courses at each institution. This will help to legitimize and enforce the ideas in their minds. As with any course, enrollment must be limited, especially in light of the case discussions. Ideally, we would like our students to be natural leaders and not be intimidated by the thought of speaking in front of large groups of people. But realistic expectations of student behavior and practical considerations will limit section sizes to thirty or fewer, with a preferred size of twenty.

The teaching methods and teaching materials are highly interdependent. A practice-based industrial focus in the classroom needs to be reinforced by a similar focus in the textbook, homeworks and laboratories. Since no single existing textbook contains both an industrial focus and engineering content, we have chosen to use a collection of existing materials. In the future, we hope to be able to use a single text, developed either by ourselves or by others. We believe that this hands-on teaching approach has significant benefit for the teaching of this material, and should be adopted more widely.

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Biographical Information

ROBERT P. SMITH is an Assistant Professor in the Department of Industrial Engineering completed his Ph.D. at the M.I.T. Sloan School of Management in 1992. He joined the University of Washington Industrial Engineering Department after a post-doctoral fellowship at the Cranfield Institute of Technology in the U.K. His research and teaching are in the area of engineering design management. He is a registered professional engineer.

RUSSELL R. BARTON is an Associate Professor in the Department of Industrial and Manufacturing Engineering at Penn State. His research and teaching are in process and simulation optimization, design of experiments, and concurrent engineering. He is an executive board member of the Leonhard Center for Excellence in Engineering Education at Penn State.

CRAIG A. NOWACK received his B.S. in Mathematics from SUNY College at Brockport, and is currently a graduate student in the Department of Industrial and Manufacturing Engineering at Penn State. He has participated in the development of two courses at Penn State: Process Quality Engineering and Concurrent Engineering, with a particular focus on the teamwork module for the concurrent engineering course.

JOSÉ L. ZAYAS-CASTRO is MEEP Co-Principal Investigator for the University of Puerto Rico - Mayagüez. Dr. Zayas conducts research and consulting in statistical process control, productivity improvement, information flow and office automation, manufacturing and business strategy, economic and cost analysis, manufacturing and business strategy, manufacturing simulation, and general management. He is a professor in the Industrial Engineering Department, for which he served as department head between 1987 and 1990.

