Product Development In The Curriculum: One Clean-Sheet Approach

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ABSTRACT

The National Center of Excellence for Advanced Manufacturing Education has been established in Dayton, Ohio with an award from the National Science Foundation's Advanced Technological Education program in October of 1994. The primary goal of the program is to develop a curriculum with advanced manufacturing as its focus. The curriculum will begin in the junior year of high school and extend to a two-year associate degree and through a four-year bachelor of science degree in Engineering Technology. The program will include opportunities for industrial employment throughout the student's education. The curriculum is currently being built with a number of "clusters" while ensuring a high degree of collaboration among clusters.

The Product Development Cluster is currently being defined and developed. The cluster is designed to address the process of analyzing customer needs, volume demands, and market requirements, conceptualizing and designing a product to meet those needs, designing the manufacturing processes, and launching the product into production. Modules within the cluster include conceptual design, computer aided design, and product development and testing, for example.

The cluster is being designed to be broad based, while maintaining a technical manufacturing perspective. The key skills within the cluster have been defined and the topics, sequencing, and method of learning and experiencing are being developed. Innovative pedagogical strategies are being developed and integrated throughout the program. Also the interaction with other modules such as Production Operations, Quality Management, and Materials and Manufacturing Processes is being developed.

This program will result in better qualified technical employees for manufacturing industries and also a path for students to get involved with Engineering schools early in their academic careers. Both the results and the process to achieve the results are presented here.

OVERALL STRATEGY

CURRICULUM

The curriculum definition process followed three phases: Preliminary Benchmarking, Detailed Design, and External Validation.

Preliminary benchmarking. Realizing that a significant amount of work has already been done by groups from industry and academia in the area of skills requirements, the Curriculum content team focused on

identifying best practices with respect to manufacturing skills. Key sources included, but were not limited to, the following:

Secretary's Commission on Acquiring Necessary Skills (SCANS)
Society of Manufacturing Engineers (SME) Curricula 2002
National Council of Teachers of Mathematics
State and local Tech Prep Consortia from the states of Ohio and Washington

In addition to these external sources, project team members reviewed existing courses at Sinclair and the University of Dayton to identify key manufacturing-related content across all academic programs. Overall, this benchmarking process yielded an initial list of over 800 discrete competencies that might be appropriate for the curriculum.

Detailed Design. For purposes of discussion and review, the list of 800 competencies was summarized into a list of 175 skill sets. These skill sets were then organized into nine “clusters,” or major thematic sets of modules. Clusters will ultimately provide an organizational structure for curriculum modules, facilitating both development and implementation. The 175 skill sets provided the framework for review and input from external stakeholders from industry, high schools, community colleges and universities.

Through the iterative process of reviewing, editing, and prioritizing individual competencies, a group of skills emerged as being so important to the success of students entering technical careers that they need to be addressed uniquely in the development of curriculum materials. These core competencies will be introduced to students early in the high school curriculum, and will be reinforced and demonstrated throughout the secondary and undergraduate programs. Upon graduation, these core competencies will be second nature to students, who will use them in all aspects of their professional lives to solve problems and manage processes. The core competencies identified are shown in Figure 1.

External Validation. A process has been defined to solicit meaningful input into the proposed curriculum modules and their content. An individual will be identified to “champion” the process, which includes the following steps:

1. Develop method for documenting input from key stakeholders.
2. Conduct interviews with representatives from industry and academia, reviewing the content of the modules and noting suggested additions, deletions, and comments.
3. Identify regional champions at partnering community colleges to replicate the process.
4. Incorporate results into curriculum modules.

Scientific Methods

Use Scientific Processes to formulate questions and plan investigations; collect and interpret data; formulate and revise explanations and models using logic and evidence; analyze alternative explanations and models proposed by others; communicate and defend scientific conclusions.

Oral Communications

Effectively communicate with, listen to and respond to others interpersonally, in teams or through presentations.

Written Communications

Demonstrate the ability to write with a purpose, in different formats, for a variety of audiences, and to organize, synthesize and communicate the significance of either technical or non-technical information.

Teamwork

Demonstrate in a group, a cooperative effort to evaluate, solve problems, and develop and implement plans and procedures.

Diversity and Fair-Mindedness

Demonstrate a willingness to fair-mindedly assess the moral viewpoints or reasoning of others, regardless of one's own bias, as well as a willingness to imaginatively put oneself in the place of others in order to genuinely understand them.

Global and Societal Awareness

Demonstrate an awareness of the relationship between each module and the local, national or global community.

Career Applications

Demonstrate how major concepts and processes of each module are applied to careers in science and technology.

Figure 1: The Guiding Principles

METHODOLOGY

The development of individual curriculum modules continues to be a significant undertaking. Numerous high school teachers and college faculty from around the country will be involved in various aspects of curriculum development. In order to ensure a high-quality product and consistency from module to module, a structured approach is required. Significant effort has been placed in developing a methodology that builds the core values of the Center into each module without limiting the creativity of the author. In order to arrive at this methodology, the project team developed policies regarding pedagogy and the use of technology in the classroom. The term “technical architecture” was adopted to emphasize the need for a common approach to instructional technology throughout the curriculum. Methodology requirements were defined by creating a prototype interdisciplinary curriculum module and documenting the process. Pedagogy, technical architecture, and the core competencies discussed in the previous section were integrated into the module development methodology.

Pedagogy. The pedagogy team developed 15 statements which define the learning theory that will drive the activities of the Center. The foundation for this learning theory is constructivism, with a commitment to preparing the student for lifelong learning. Through the core competencies, a high emphasis is placed on critical thinking and analytical problem solving skills throughout the curriculum. The 15 statements are shown in Figure 2.

1. Learning is a lifelong process.
2. Learners construct their own knowledge and understanding of the world in which they live.
3. Learners search for tools to help understand their experiences.
4. Learners come to classrooms with different backgrounds, knowledge, skills, values and experiences.
5. Learners have preferred modes of learning. Activities need to be structured so learners can utilize their preferred mode of learning as well as have the opportunities to develop skills in using other modes of learning.
6. Learners must be active participants in the learning process.
7. Learners need opportunities for real, hands-on and/or concrete experiences.
8. In learning situations, learners are challenged to build on past experiences to create new schemas or structures.
9. In a learning situation, learners are allowed to explore, experiment and discover.
10. If learners see the value of the learning, they will become active seekers of knowledge and will assume responsibility for the learning.
11. Learners grasp the meaning of concepts more easily when they go from “whole to part” rather than “part to whole.”
12. Learners need opportunities to develop metacognitive and intrapersonal skills and need time to reflect on their learning.
13. Learning to learn is an important skill that needs to be emphasized in all content areas.
14. All areas of development, which includes the areas of motor, thinking, language, social-emotional, are used when a learner is in a “learning situation.”
15. A higher degree of learning occurs when the experiences are integrated, which involves many different subjects and skills being used at the same time. Learning is not integrated when each subject is treated separately and learners are expected to integrate the subject matter and skill at some future date.

Figure 2: The 15 Learning Statements

Technical Architecture. Focused effort was placed in determining strategies for the use of instructional technologies in the curriculum. Decisions regarding platform, operating system, and authoring tools must be made. One source of input is a survey of high schools to determine their technological capabilities. The team is also seeking input from other curriculum development projects at community colleges and universities to determine the state-of-the-market in this key area.

Methodology Prototype. A team comprised of instructors from Industrial Engineering Technology, Accounting, and Quality Engineering Technology was charged with developing an interdisciplinary curriculum module, Manufacturing Performance Measures, and documenting the overall process outline. This outline provided the framework for the module development methodology. A set of materials for module authors was assembled to support them in the module development process. These materials will include key milestones, strategies for the inclusion of pedagogical principles and core competencies, and guidelines for the use of instructional technologies. The methodology will also include a process for involving key stakeholders from industry, secondary, and post-secondary education in the development process.

MODULAR STRUCTURE OF THE CURRICULUM

The Product Development Module is one of nine modules in the curriculum. Recognizing that the overall learning experience is only as effective as each distinct component, each module is set up to relate to the curriculum architecture, and to leverage learning.

Modules rely on a constructivist approach, and each one is designed to help students master a relatively small set of select competencies. In combination, however, a cluster of modules must build a broad range of knowledge and competencies specific to each student's program of study, and they must guide students through the synergistic learning experience.

Defining Core Concepts. Each module must integrate two perspectives: 1) the immediate perspective, or how the knowledge and competencies can be used to succeed in the planned learning tasks; and 2) the long-range perspective, or how the knowledge and competencies can be used to succeed in the students' selected educational programs and work environments. To accommodate these two perspectives, a pattern which permeates each module and which links each module with the broader instructional architecture has been identified. This operational pattern consists of these elements:

- The big picture
- Context
- Closure
- Generalization

Instructors launch each lesson module with the big picture, or general framework, so students can begin to envision the full breadth of situations where the module content might be applied in the world. Within the broad outlines of the big picture, the instructor delineates a module's particular context or setting. When specific learning tasks are completed and again when the module is near completion, instructors guide students through a closure and generalization process, to help them connect their recent learning experience back to the world.

To accomplish these connections, learning perspectives are forecast in the form of the big picture and context at the beginning of each module. At the end of specific learning activities, these perspectives are revisited in the form of guided closure and generalization. Figure 3 illustrates the dynamics of this instructional/learning mode.

PRODUCT DEVELOPMENT CLUSTER

Role of the Product Development Cluster. The graduate of this program will be a Manufacturing Operations Technician. The objective of the Product Development Module is to ensure the graduate of this program has the ability to serve as the manufacturing representative to a product development team, and to contribute to the team immediately upon graduation. As a part of a product development team, the manufacturing operations technician will participate in the process of analyzing customer needs, volume demands, and market requirements and conceptualizing and designing a product or service to meet those needs, demands, and requirements. The technician's primary activity will be simultaneously designing the process to produce and distribute the product or service in the most productive and least costly manner possible and launch the product into production.

Fig. Instructional/Learning Mode

Desired Capabilities. Certain abilities must be attained by the student in order to be able to contribute significantly as the manufacturing representative to a product development team. As a basis for developing the curriculum, a broad list of desired abilities has been developed. While all of them cannot be attained, a list such as this needs to be developed so that conscious decisions about the mission and inevitable trade-offs can be made. These abilities are listed below.

- Foundational/Core:
 - Materials and manufacturing processes
 - Manufacturing systems and controls
 - Quality Management
 - Operations and Inventory Control
 - Mechanical Design Basics
- Product Development Tools:
 - Quality Function Deployment
 - Design for Manufacturing and Assembly
 - Cost Estimating
 - Failure Modes and Effects Analysis
 - Ergonomics and Industrial Design
 - Rapid Prototyping
 - Patent Searching
 - Competitive Benchmarking
 - Design Reviews/ Decision Analysis
 - Testing - performance, reliability, durability
 - Metrics for Product Development
- Business and Management Tools:
 - Engineering Economics
 - Supplier development and certification
 - Capital Justification
 - Marketing and Strategic Planning
 - Market Research
 - Meeting management
 - Team management
 - Project management
- Conceptual Design:
 - Invention-creation-imagination
 - Design concepts
 - Ingenious mechanisms

Pedagogical Approaches. Learning to achieve the above abilities could be done with a wide variety of pedagogical methods. In keeping with the core competencies and learning statements, a variety should be employed. Again, all of these approaches do not apply to all topics or possibly to any topic, but it is important to consider all possibilities so that paradigms are challenged. Possible approaches that apply to gaining the above capabilities are listed below:

- Case approach:
 - Past successes
 - Past failures
 - Fictional
- Software approach:
 - Commercial software:
 - Boothroyd and Dewhurst
 - Ford's FMEA
 - QFD
 - Computer Aided Design
 - Mechanical simulation such as Working Model
 - Factory floor simulation packages
 - Student generated software:
 - Spreadsheets for analysis and decision matrices
 - Basic programs written to analyze economics or track processing alternatives
- Teardowns and reverse engineering:
 - Mechanical and Electromechanical devices- VCR, printer, telephones, power tools, fans, cylinders, pumps
- Build approach:
 - Use hardware to build simple items: catapults, clock motor devices, gadgets.
- Lecture
- Discussion
- Research Project:
 - Laboratory Experience
 - Individual Project
 - Team Projects
 - Tours

Original Literature Sources. Students should graduate with a familiarity with the contemporary authors within the industrial community. To that end, the program should not be built solely on traditional textbooks, but original sources commonly used in industry. Examples include Jim Womack, Preston Smith, Boothroyd and Dewhurst, Henry Ford, Peterson, Iaccoca, Kitter and others.

Level of learning. All areas will not receive the same amount of attention in the cluster. The vocabulary that has developed to represent this is Introductory, Reinforcement, and Mastery. As the curriculum continues to take shape, the project team needs to decide whether a student needs to be conversant, knowledgeable, proficient, or expert in a given area.

The Module's Role in the Product Development Cluster. Beyond deciding what a student needs upon completion of the program, the cluster teams work together to decide how they relate together. Each desired capability or competency must be considered as to how it fits into the categories below:

Must be learned before this module - prerequisite
Primary - teach it here
Reinforcing from another earlier module
Preliminary - introduce here, will be taught later
Omit - simply will not be able to address this item

Current Modules with Product Development Cluster

Each competency that was identified needs to go through a process of determining its emphasis in the program, its fit in this cluster, the most appropriate pedagogical approach, its relationship to current literature and software. This process is ongoing with the cluster team. The proposed curriculum for the cluster is constantly changing, but the current state at the time of this writing is shown below:

Modules and Competencies:

CONCEPTUAL DESIGN

- Participate on a product development team.
- Work with sales and marketing professionals to identify customer needs.
- Convert customer needs into conceptual designs, prototypes, and detailed designs of the product or service to be marketed.

Prerequisite: Marketing (EM03)

COMPUTER AIDED DESIGN

- Demonstrate basic skill in the production of product design drawings as represented in three dimensions in a CAD system.
- Interpret product designs represented in a CAD system in terms of the expected geometrical features of the product and the tolerances on critical dimensions.

PRODUCT DEVELOPMENT AND TESTING

- Plan and implement test and rapid prototyping procedures during the design process to ensure that the product is fit for the customer use.

- Use “Design for X” techniques to ensure that the product exhibits satisfactory durability, reliability, safety, serviceability, manufacturability, and minimum environmental impact over the expected length of the product life cycle.

Prerequisites: Conceptual Design; Computer Aided Design; Drawing and Sketching

PROCESS DESIGN

- Specify and/or design materials, manufacturing processes, equipment, and production methods to ensure effective, high quality, and cost effective production of the product.
- Minimize the time to market.
- Plan for production in adequate volumes.

Prerequisites: Pertinent modules from this cluster and *Materials and Processes Cluster*.

SIMULATION TECHNIQUES

- Analyze forces and moments on structures and components of structures.
- Determine the location of the centroid and moment of inertia for areas and volumes.
- Use the concepts of equilibrium to solve for unknown forces and moments.
- Use the principles of friction to solve problems with significant frictional forces.

Prerequisite: Equilibrium: Newton’s First Law.

STRENGTH OF MATERIALS

- Analyze the effects of forces and moments on structures and components of structures to determine the resulting stresses and deflections.
- Analyze components and structures for direct axial stress, direct shear stress, torsional shear stress, and bending stress in beams.
- Analyze columns to determine allowable axial load to preclude buckling.
- Analyze components and structures to determine deflections and deformations due to direct axial loading, bending, torsional shear, and thermal effects.

Prerequisites: Statics; Metallic Materials

DRAWING AND SKETCHING

- Prepare technical drawings and free hand sketches of mechanical components using orthographic projection techniques.
- Show dimensions for all features of components on the drawings.

Summary

Product development must be a vital part of any manufacturing program. Now that the manufacturing entities are invited into the early stages of product development, manufacturing personnel must be prepared to contribute to the process. It is not often that a program can be initiated with a “clean sheet” as a starting point. The project team has paid particular attention to the process of developing the program as well as to its content.

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