National Center of Excellence for Advanced Manufacturing Education

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Abstract

This paper reports on the NSF-sponsored National Center of Excellence for Advanced Manufacturing Education. The center's objectives are to develop and disseminate novel manufacturing education approaches that address competency gaps and prepare BS and associate degree graduates to contribute to the long-term improvement of U.S. manufacturing capability.

National Center Of Excellence For Advanced Manufacturing Education

The National Center Of Excellence For Advanced Manufacturing Education (NCE/AME) was established in Dayton, Ohio in January, 1995 with support from the National Science Foundation (NSF).* The center is based in the Advanced Integrated Manufacturing Center (AIM Center) that is jointly operated by Sinclair Community College and the University of Dayton.

The NCE/AME was one of the first three centers funded by the NSF under the Advanced Technological Education Program (ATE). The center's objectives are to develop and disseminate novel manufacturing education approaches that prepare BS and associate degree graduates to contribute to the long-term improvement of manufacturing capability in the United States. Innovations in curriculum design, content, and pedagogy are being developed.

Additional objectives are aimed at improving mathematics and science education in grades 11 and 12 of secondary schools by providing educational materials that emphasize the application of fundamental concepts to authentic applications, typically relevant to manufacturing careers.

Faculty development for high school, community college, and university faculty members is another important objective.

Initial funding for the center was for three years from January 1, 1995 through December 31, 1997. The work of the center will continue through the end of the year 2000 with three years of additional NSF funding. Continuation is planned beyond 2000 with revenues derived from a variety of sources.

While based in Dayton, Ohio, the work of the center is being carried out by a very large, geographically dispersed team of professionals from academia and industry. This has been done for several reasons. The planned wide implementation of the results of the Center's efforts should be facilitated by having contributors from several areas of the country. The wider variety of industry types and specific industries recruited as contributors to the module development process should provide significant additional validation of the competencies contained in the program and a more useful curriculum design.

Curriculum Design - Addressing Needs Of Manufacturing Industries

The primary outcomes of the center's work are a novel associate degree curriculum in manufacturing engineering technology and a competency-based, modular, activity-based program and pedagogy. The target employer for the graduate of the associate degree program is any product-producing industry. Skills are built in modern manufacturing processes, materials, lean manufacturing, just-in-time, quality, continuous improvement, and customer satisfaction to prepare graduates to be strong contributors to world-class industrial production operations.

These skills are central to overcoming the gaps in manufacturing education as identified by the 1996 study conducted by the Society of Manufacturing Engineers (SME) called the *Manufacturing Education Plan: Phase I Report*.[1] This report gives conclusions from a major national study in which manufacturing professionals from several different industry sectors reported where they perceived gaps between the competencies of graduates of manufacturing education programs and the needs of their industry.

The curriculum and pedagogy innovations being developed by the NCE/AME were well along toward addressing those competency gaps even before the study commenced. One reason was that the curriculum design was guided to a large extent by SME's *Curricula 2000*[2] and *Curricula 2002*[3] studies. The recommendations of these two studies seem consistent with the conclusions of the SME Manufacturing Education Plan. Thus the products of the NCE/AME have been developed since 1995 to address the competencies identified in the 1996-97 study.

The curriculum includes strong foundations in mathematics, science, and communication; and six clusters of manufacturing oriented modules. The manufacturing clusters are:

- Manufacturing Processes and Materials
- Production and Inventory Control
- Quality Management
- Design for Manufacturing
- Manufacturing Systems and Automation
- Enterprise Integration

More detail about these clusters is given later in this paper.

Pedagogical Innovations

The *guiding principles* for module development ensure that important skills are developed not only in focused modules but also within virtually all modules through the authentic learning tasks. Included are skills of planned inquiry, teamwork, oral and written communication, diversity and fair-mindedness in interpersonal relations, and global and societal awareness. A later section of this report expands the discussion of the guiding principles.

An activity based learning theory based on constructivist principles guides the development of the learning modules. The use of the lecture mode is minimized in favor of involving students in a series of hand-on exercises called *authentic learning tasks*.

The pedagogy also employs the educational principle that students learn best when working with concepts on a *whole-to-part* basis. Each module starts with the big picture in which learners, guided by the facilitator (instructor), consider a wide range of authentic contexts in which the competencies contained in the module are used. Some of those contexts are then the focuses of four to six *authentic learning tasks* that mirror the way the desired competencies are used in a

high-performing industry. The desired competencies are first learned through the activities that make up these experiences.

But the learning theory used also emphasizes that learning and understanding are enhanced when the learner transfers that learning to a different context. Thus each module ends with a more comprehensive *transfer activity* that applies the module's competencies. Most of the modules will use the integrating manufacturing experience, described next, as that transfer activity.

The program concludes with a sizable capstone experience in which learners will apply many of the concepts and skills from the entire program to a current industrial application.

Objectives Of The Clusters Within The Curriculum

A summary of the primary objectives of each of the nine clusters of modules that make up the proposed associate degree manufacturing engineering technology curriculum illustrates the approach being taken to address the needs of industry in an academically strong program.

Principles of Science. Science modules are designed to develop systematic thinking skills including the ability 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; and communicate and defend scientific conclusions. The entering student is expected to have completed the proposed 12th grade science standards. Principles of physics mechanics, thermal science, and inorganic and organic chemistry are included.

Mathematics. Competencies in precalculus, probability, statistics, and the basics of calculus are included as appropriate for use by a manufacturing engineering technician and on which further study in mathematics can be built. Completion of the proposed 12th grade mathematics standards prior to entry is expected.

Humanities, Communication, & Team Building. The manufacturing engineering technician must examine the challenges faced by humankind in the evolving technical world and confront the philosophical, ethical, and sociological dimensions of the technical environment. The learner must interact appropriately with people of diverse backgrounds, communicate clearly, and participate effectively in a team environment that capitalizes on group synergy.

Manufacturing Processes and Materials. The core set of competencies that manufacturing engineering technicians must possess include an understanding of the systems concept of manufacturing that integrates a design, engineering materials, and manufacturing processes into a created product. They will be able to plan, organize, implement, and manage the transformation of raw stock in accordance with product design specifications. A knowledge of the structure and properties of engineering materials, both metallic and non-metallic is essential. Emphasis is on establishing efficient production systems and solving industrial production problems.

Production and Inventory Control. The manufacturing engineering technician will plan, analyze, and control the production of products from the acquisition of raw materials through the production and distribution of the products to customers. Included will be the planning and implementation of facilities for production, the effective management of inventory, the

implementation of lean manufacturing concepts, and the continuous improvement of manufacturing operations.

Quality Management. The manufacturing engineering technician will work with the quality professionals in the enterprise to help meet customer expectations and achieve customer loyalty. The ability to apply the principles and practices of the foundations of quality, process control, measurement and calibration, and continuous process improvement must be demonstrated.

Design for Manufacturing. As part of a product realization team, the manufacturing engineering technician will participate in the process of analyzing customer needs, volume demands, market requirements, and conceptualizing and designing a product to meet those requirements. Primary emphasis is on concurrently designing the processes to produce the product in the most productive and least costly manner possible and to launch the product into production.

Manufacturing Systems, Automation, and Control. The manufacturing engineering technician will plan, design, implement, use, and troubleshoot manufacturing systems and controls to monitor production quantities, costs, and quality; provide automated production where appropriate; and integrate manufacturing operations with enterprise management systems. Emphasis is on electronic controls, programmable logic controllers, fluid power, computer numerical controlled machining, data acquisition, and robotics.

Enterprise Integration. The manufacturing engineering technician is a key player in a manufacturing enterprise who works with information from product designers, vendors, customers, sales and marketing staffs, and enterprise managers, and provides the systems to deliver products to customers. Information resulting from the manufacturing operations is then used manage the enterprise. The technician should therefore have knowledge of supply chain management, manufacturing information systems, principles of marketing and customer satisfaction, financial management, and measures of performance.

Guiding Principles For Module Development[4]

The Guiding Principles for module development were established early in the project to define a systematic framework within which all content will be taught. Rather than focusing on what the students should know, the Guiding Principles deal explicitly with how students think, how they communicate, how they interact with others, and how they use knowledge.

Students only learn to think in scientific ways if they practice that mode of thinking repeatedly and in a wide variety of situations. Every module will provide explicit practice in scientific thinking skills, ranging from the more academic tradition of scientific disciplines to applications of the "Plan-Do-Study-Act" cycle in manufacturing planning and continuous improvement processes.

Similarly, every module will provide planned practice and reinforcement of oral and written communication skills and of teamwork skills - not just because these skills are valuable in themselves, but also because their use aids in the overall learning process. When students write, talk, and work with others in positive ways, they learn more.

In each instructional module, students will practice and enhance the following competencies:

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; and communicate and defend conclusions.

Oral Communications. Effectively communicate with, listen to, and respond to others interpersonally, in teams, and 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 system performance, 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.

Integrating Manufacturing Experience

The program design being developed by the NCE/AME implements the concept of the transfer activity through an *integrating manufacturing experience*, in which the student gains an understanding of how each manufacturing oriented competency acquired is used in authentic activities within a single enterprise. Students learn about the many functions that exist in a manufacturing enterprise and how they must be integrated. The connections among the several modules are also better understood because of this feature of the pedagogy.

Educational institutions implementing the program are encouraged to identify a manufacturing enterprise that is appropriate to its market area on which to base the integrating manufacturing experience for its program.

The ideal model would be to actually employ the students in a real, product-producing company. Thus they would see on a daily basis the application of their learning to real product development, manufacturing planning and control, quality management, manufacturing processes and equipment, production and inventory control, automation, and other features of an integrated enterprise. A notable example of this approach is *Focus HOPE* in Detroit, Michigan.

It is recognized that this may be impractical in many institutions. In such cases, the program design calls for the development of a very realistic model company.

The pilot implementation of the program at Sinclair Community College in Dayton, Ohio has created *Robotic Grippers, Inc. (RGI)* as a model that serves to illustrate the concept. A rather complete description of this hypothetical company has been developed that designs, manufactures, and delivers a line of standard and special-purpose grippers for use in a variety of robotic material handling applications. Product designs and specifications with real prototypes are now available.

The organization of RGI has been described in a comprehensive manual that includes product engineering, manufacturing engineering, facility and equipment layout, production, quality management, purchasing and material control, marketing and sales, and the business functions of enterprise management. A customer base and a chain of suppliers has been defined.

The main components of the robotic grippers are to be manufactured by RGI in its own facilities. Particular emphasis is on CNC machining, plastics processing, and assembly. However, it has more than one plant and it serves a global market. Students experience the issues of integrating a multi-site operation and the consideration of cultural differences in other parts of the world. Also, RGI acquires some components for its grippers from vendors and therefore supply chain management is an issue with which students deal.

Production of a line of standard products to customer order allows students to consider various aspects of lean manufacturing, including materials management, setup time reduction, one-piece flow, and just-in-time production operations.

Because RGI often is asked to develop special grippers for unique applications, the principles of marketing, specification of customer requirements, conceptual design, design for manufacturing and concurrent engineering, and production planning must be demonstrated by students.

A novel approach to adding realism to *Robotic Grippers, Inc.* is that the director of the manufacturing engineering technology program serves as the "plant manager" for RGI. He is available for consultation about details of the company's operations and management. He frequently visits classes in which RGI is being used as a basis for an activity.

The examples that follow illustrate how the integrating manufacturing experience is built into various modules.

Module	***Transfer Activity - RGI***
Conceptual Design	Design new, unique gripper fingers for a customer
Quality Foundations	Establish and enforce quality standards for grippers
Metallic Materials	Specify an aluminum alloy for body of grippers
CNC	Write CNC program for new design for gripper fingers
Just-in-Time	Production planning for an order for a new customer
Data Acquisition	Design a system for monitoring production quality data
Customer Satisfaction	Create marketing plan for grippers to reach new customers

Note that students will have addressed several other contexts while initially learning the competencies in a module so they develop a broad understanding of how the competencies can be applied, not just within the integrated manufacturing experience.

A cooperating institution in Virginia has developed its own, locally-based implementation of the integrating manufacturing experience. It has set up a consortium of companies that employ its graduates and is using real applications from them as transfer activities. Each company is viewed as a part of a supplier chain to an original equipment manufacturer. This approach gives students access to a variety of potential employers; demonstrates the business relationships among several companies; and exposes the students to a wide variety of manufacturing processes and systems.

Accreditation Issues

The organization that accredits academic programs in manufacturing is the Accreditation Board for Engineering and Technology (ABET). Engineering programs are assessed against criteria set by the Engineering Accreditation Commission (EAC) and criteria for engineering technology programs are set by the Technology Accreditation Commission (TAC). In each case, the specific criteria for manufacturing programs are set by the Society of Manufacturing Engineers.

The curriculum design and pedagogy espoused by this project are supportive of the SME-sponsored program criteria that call for each institution to identify its own mission and to design the program to accomplish that mission.

The general criteria of both EAC and TAC are evolving toward more outcomes-based assessment and away from tight specification of program content. It is planned that the program being designed will meet the eventual criteria established by the Technology Accreditation Commission.

Also related to these accreditation issues, the project is developing authentic assessment approaches that guide instructors in the assessment and evaluation of student competency by observing the quality of student work while the authentic learning tasks and transfer activities related to the integrating manufacturing experience are being completed. Such assessment techniques should aid institutions in the process of verifying to accreditation teams that student outcomes are consistent with the program's mission.

The modular structure of the program will require that the program be evaluated as a non-traditional program in the near term while existing, more structured criteria are being used. Encouragement to pursue the more flexible modular approach has been given by several members of TAC, the ABET headquarters staff, and others actively involved in accreditation processes.

Industry Involvement In Module Development

From the beginning in 1994, the NCE/AME program development has been industry driven.

- The initial list of competencies to be included in the program were derived from interviews with industry professionals and from published reports of what industry expects from graduates of manufacturing education programs.
- Each module is being developed with the aid of an *industry champion*, a professional from an industry that practices the competencies of the module at a world-class level. The champion verifies the appropriateness of the competency statements, helps to identify authentic learning tasks, provides real contexts for some of the activities, and reviews the final document.
- Authentic assessment and evaluation techniques are being developed with industry consultation that should lead to an assurance that graduates can, indeed, apply the competencies learned in the program to industry's needs.
- Additional external reviews of modules are being requested from other industry professionals.
- Several industries have become users of some of the modules and others have had special modules designed for their particular needs using the pedagogy developed by the NCE/AME.

Tools For The Future Module

An important example of industry involvement in learning module development is the creation of a unique course called *Tools for the Future*. The course is designed to increase the ability of industry associates at all levels to collaborate, cooperate, and communicate to solve tough problems on the job. The Dayton Tooling and Machining Association worked with the staff of the AIM Center to develop a 3-hour per week, 12-week course based on two important works, *The Seven Habits of Highly Effective People*[5] by Stephen Covey and *The Goal*[6] by Eli Goldratt.

Teams of company employees learn basic concepts of the theory of constraints in a work environment and apply the tools associated with the logical thinking process used in problem solving. As of the Fall of 1997, 180 people have completed the course and more are in process. In February, 1998, the course will be presented to the annual meeting of the National Tooling and Machining Association with a recommendation that it be replicated throughout its system of local chapters. This industry-driven course has been adopted as a part of the curriculum being developed by the NCE/AME.

Status Of Module Development

The current curriculum design calls for 66 instructional modules to be included in the associate degree manufacturing engineering technology program. Modules average approximately equivalent to one quarter credit each. Seven other courses are planned to be drawn from the traditional curriculum in such areas as humanities, social sciences, English composition, and the fundamentals of oral communication. The capstone experience completes the curriculum.

The development of 17 modules took place during the first three years of the project from January, 1995 through December, 1997 along with the creation of the curriculum and the pedagogy. Of these, four were directed toward secondary level instruction while the remaining 14 are at the associate degree level. Over the next three years through the end of 2000, 14 new associate degree modules will be developed while all are taken through both alpha and beta testing. Thus, by January 1, 2001, the NCE/AME plans to have 31 modules published and available for adoption. The other modules will be developed as resources are available.

How The National Center Of Excellence For Advanced Manufacturing Education Addresses SME-Identified Competency Gaps In Manufacturing Education

The Society of Manufacturing Engineers (SME) conducted a major, industry-based study[1] from August, 1996 through June, 1997 to identify competency gaps experienced by graduating manufacturing engineers and technologists. The most frequently mentioned gaps included:

- Communication skills and teamwork
- Business and project management skills
- Materials and manufacturing processes
- Lean manufacturing and continuous improvement
- Quality principles, statistics and probability
- Ergonomics and human factors
- Continuous, lifelong learning

While emphasizing these gaps, it was presumed that graduates must continue to demonstrate the high level of technical competence that industries have come to expect from graduates of U.S. colleges and universities.

The complete curriculum and the pedagogy being developed by the NCE/AME project will address virtually all the competency gaps identified by industries in the SME study at the level appropriate to an associate degree in manufacturing engineering technology. It has heavy emphasis on communication skills, teamwork, concurrent engineering, manufacturing processes and materials, quality management, lean manufacturing, customer focus, supply chain management, productivity improvement, inventory planning and control, just-in-time methods, KANBAN, and other aspects of world class manufacturing. All were mentioned in the SME study as being important competencies for graduates of manufacturing education programs.

The graduates of this program should be job-ready to provide valuable service to product-producing industries through unique program features such as:

- The students' participation in numerous team-based learning activities throughout the program,
- The development and use of oral and written communication skills in every instructional module,
- The development of strong computer skills,
- The demonstration of a broad set of technical competencies that are built upon strong science and mathematics fundamentals,
- Primary emphasis on core manufacturing processes, materials, manufacturing systems, and automation,
- The inclusion of significant competencies in design for manufacturing, quality, production and inventory control, and business-oriented enterprise integration concepts.
- Its emphasis on competency based instruction,
- The use of activity-based, authentic learning tasks that emphasize learning through inquiry using scientific methods,
- The further use of learned competencies through completion of transfer activities all related to an integrating manufacturing experience,
- Generalization of principles learned that will lead to the ability to apply concepts to many different contexts and to continue intellectual development through life-long learning,

Faculty Development And Dissemination Activities

Faculty development and dissemination activities for the curriculum project have involved a variety of opportunities to share information, train facilitators, and gather input. These range from one hour overview presentations to a week long workshop where participants draft and revise portions of modules.

Sessions at numerous state, regional, and national professional meetings of engineers and of educators have included practice with authentic learning tasks, discussion of guiding principles, review of assessments, and analysis of transfer activities. A five day workshop with the Manufacturing Technology Center in southwest Virginia is an example of an intensive off-site program tailored to specific needs. The participants learned about module development then completed tasks critical to the success of the local manufacturing education program.

Another example is the expansion and ongoing change of the nature of faculty development at Sinclair which has resulted in an institution-wide reform grant from NSF to support creation of a

parallel college. A significant portion of this work will be module development employing the principles, guidelines, and teaching and learning strategies from the Center's main project.

In cooperation with the Miami Valley Tech Prep Consortium, two faculty development programs are reaching secondary and post-secondary teachers, counselors, and administrators each summer. Tech Odyssey (a one week snapshot of area industries and needs for the future) and TIES: Teachers in Industry for Education Support (a three week externship with deliverables) will be offered for the third year in 1998. The dissemination process is closely intertwined with faculty development as science, mathematics, and manufacturing modules are the models for educators to modify their own practices or design new curriculum.

The success of these two summer programs and continuing dialog among several groups have led to a larger umbrella project called STAMP: Students, Teachers, and Mentors Partnerships. STAMP has been funded for two years by School-To-Work grants, the NSF grant, and the Miami Valley Tech Prep Consortium. STAMP includes student internships and mentor training for industry partners as well as support for middle school students to visit industry sites.

The faculty development and dissemination activities have enabled the NSF team to build education and industry partnerships locally and nationally, seek additional funding for spin-off activities, recruit more users and developers, and provide for a wide variety of learning styles. All of these factors contribute to a stronger resource base, a curriculum linked to the real-world, and higher skilled facilitators who will reach more students with engaging and meaningful activities which will better prepare participants for success in the 21st Century.

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[*] Partial support for the National Center of Excellence for Advanced Manufacturing Education has been supplied by the National Science Foundation under grant number DUE-9454571. Any opinions, findings, and conclusions or recommendations expressed in this paper are those of the authors and do not necessarily reflect those of the National Science Foundation.

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