

MANUFACTURING EDUCATION FOR THE **21ST** **CENTURY**

*Volume I:
Curricula 2002 Report*



Sponsored by the
Society of Manufacturing Engineers

Editor: David L. Wells, CMfgE

Published by the
Society of Manufacturing Engineers
One SME Drive, P.O. Box 930
Dearborn, Michigan 48121 U.S.A.

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DEARBORN, MICHIGAN 48121-0930

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International Standard Book Number: 0-87263-463-9

Manufactured in the United States of America

Chapter 6: Graduate Education in Manufacturing Engineering

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Donald Falkenberg; Wayne State University
Ralph Haycock; Utah State University
Winston Knight; University of Rhode Island
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6.1 Objectives ...

The Curricula 2002 panel which addressed graduate programs in Manufacturing Engineering set out to develop a concise description of the capabilities, skills and intellectual attainment which should be expected from graduates of master's-level programs. In so doing, the panel attempted to articulate the distinctions in expected capabilities, skills and intellectual attainment between undergraduate and graduate programs in Manufacturing Engineering, as well as between graduate programs in Manufacturing Engineering and graduate programs in Manufacturing Engineering Technology.

The panel focused more on expected outcomes of graduate-level Manufacturing Engineering programs and less on the actual design of the programs themselves. Insofar as possible, the panel avoided the temptation to develop a prescriptive, uniform recommended curriculum for graduate programs. A number of guiding principles and programmatic characteristics were then established to serve as guidelines for the design of graduate-level programs; the emphasis here aimed at successful achievement of the desired capabilities and competencies.

6.2 Capabilities and Competencies ...

By the year 2002, graduate-level curricula in Manufacturing Engineering should have evolved to yield master's degree holders who are prepared to conceive, plan, design and operate industrial systems for product development and realization. Their capabilities

should be applicable to virtually any manufacturing industry, to the manufacture of a wide variety of product types and to all relevant production and infrastructural roles in the manufacturing enterprise. The outcome should be graduates who have the skill and intellectual capacity to ...

innovate;
create;
develop;
interpret;
communicate;
plan;
design;
manage;
analyze;
control; and
operate

complex systems of people, materials, machines and processes to achieve globally-competitive product realization.

The master's-level-prepared Manufacturing Engineer will be expected to ...

- ... participate as a member or leader in multi-disciplinary teams that focus on issues of quality engineering and concurrent engineering;
- ... be an effective communicator, possessing the ability to interact with all levels of manufacturing practitioners [e.g., management, designers, production personnel, machine operators];
- ... be proficient in understanding process technologies and manufacturing systems;
- ... be a systematic thinker, understanding the linkages of elements in complex systems;
- ... be able to understand and respond to issues of quality, timely performance and cost-effectiveness;
- ... understand the impact of the product realization process on the environment and provide leadership to minimize environmental impact from a full-life-cycle perspective;
- ... understand the human and cultural framework that influences and constrains the technology, the organization and the human resources of the enterprise.

The master's graduate should understand the manufacturing and business objectives of the enterprise and be able to translate them into plans and actions for effective product realization. The graduate should be able to recognize the global context of competitive manufacturing. Highly developed computer skills will allow these graduates to function effectively in this globally-competitive market. These computer skills encompass ...

- ... integrated desktop applications;
- ... process control;
- ... data acquisition and distributed databases;

... product modeling and computer-aided-design [CAD] and -engineering [CAM];
... computer-integrated-manufacturing [CIM].

The essential capabilities and competencies of master's-level education in Manufacturing Engineering can be achieved through a variety of mechanisms that include formal coursework, internships, industrial experience, plant visits, practicum experience and seminars.

6.3 Guiding Principles ...

These capabilities and competencies can be achieved through a variety of mechanisms that include formal coursework, internships, industrial experience, plant visits, practica and seminars.

- Master's-level graduate programs in Manufacturing Engineering should produce graduates with stand-alone qualifications aimed at meeting the needs of industry and should not be geared solely to preparing an individual for Ph.D. studies.
- There should not be a prescribed detailed content for graduate programs in Manufacturing Engineering; no attempt should be made to create a unified graduate curriculum. Rather, each program should emphasize and evolve from the strengths which exist within a particular department and institution.
- Graduate programs should address a broad view of manufacturing, from product definition through processing, and include product life-cycle issues and socio-technological implications.
- Graduate programs should be expected to be diverse within a general framework. Individual programs should be expected to differ in curricular requirements and in ways of achieving the desired characteristics. Detailed competencies in specialized areas should be expected to vary from program to program.
- Graduate programs should be able to accommodate both full-time and part-time students with a variety of backgrounds and experiences.
- While graduate programs should accommodate students from a diverse range of backgrounds, entrants should have some understanding, either through education or experience, of ...
 - ... manufacturing processes;
 - ... materials;
 - ... manufacturing systems.

The normally-expected entrance requirement would be a Bachelor of Science degree in an engineering discipline, but graduates from undergraduate programs in physical

sciences [or their equivalent] could be accommodated through specified additional study requirements.

- Graduate programs should practice what is being taught. For example, total quality management [TQM] should be practiced within the program itself, if students are expected to comprehend these principles. Similarly, integration should be practiced within the program, if students are to understand the implications of systems integration. Teamwork should not be taught as an intellectual exercise, but must be experienced by students in supervised team-oriented curricular assignments.
- Students enrolled in graduate programs in Manufacturing Engineering should be encouraged to study topics or courses from a range of engineering and related disciplines to meet their individual career requirements or interests. In this context, it may be appropriate to establish linkages between engineering and business programs.
- It is recommended that all programs include a detailed study of a selected topic to be reported in the form of a thesis or its equivalent.
- Programs should be expected to incorporate a diverse variety of teaching and learning methods, including ...
 - ... group projects;
 - ... internships; co-operative education schemes;
 - ... case studies; seminars; speakers from industry;
 - ... laboratory experiences;
 - ... project reports; thesis.
- Graduate programs should focus on manufacturing futures, emphasizing forward thinking, rather than historical perspectives.
- Graduate programs should be concerned with advanced study in the general area of Manufacturing Engineering. Program designations may be either "Manufacturing Engineering" or "Manufacturing Systems Engineering", and the title should reflect the orientation of the studies. Graduate-level education in certain aspects of Manufacturing Engineering will also take place as an option within a traditional discipline -- most often, Mechanical Engineering or Industrial Engineering.

6.4 Characteristics of the Master of Science Program ...

The Master of Science in Manufacturing Engineering [MS MfgE] builds on a professionally accredited bachelor's-level engineering program. While it is not the norm, students may also enter graduate programs in Manufacturing Engineering with undergraduate backgrounds in physical or computer sciences. At a minimum, entering students must have

an analytical background with foundation knowledge in materials science or engineering and in manufacturing processes.

Graduates of master's degree programs in Manufacturing Engineering will be expected to have the requisite skills to solve real-world manufacturing problems. It is unrealistic to expect that each and every student will have in-depth knowledge of all aspects of manufacturing. Thus, the specific educational objectives of the particular master's program in Manufacturing Engineering should be designed to provide graduate-level education in manufacturing characterized by both breadth and depth of knowledge and experience.

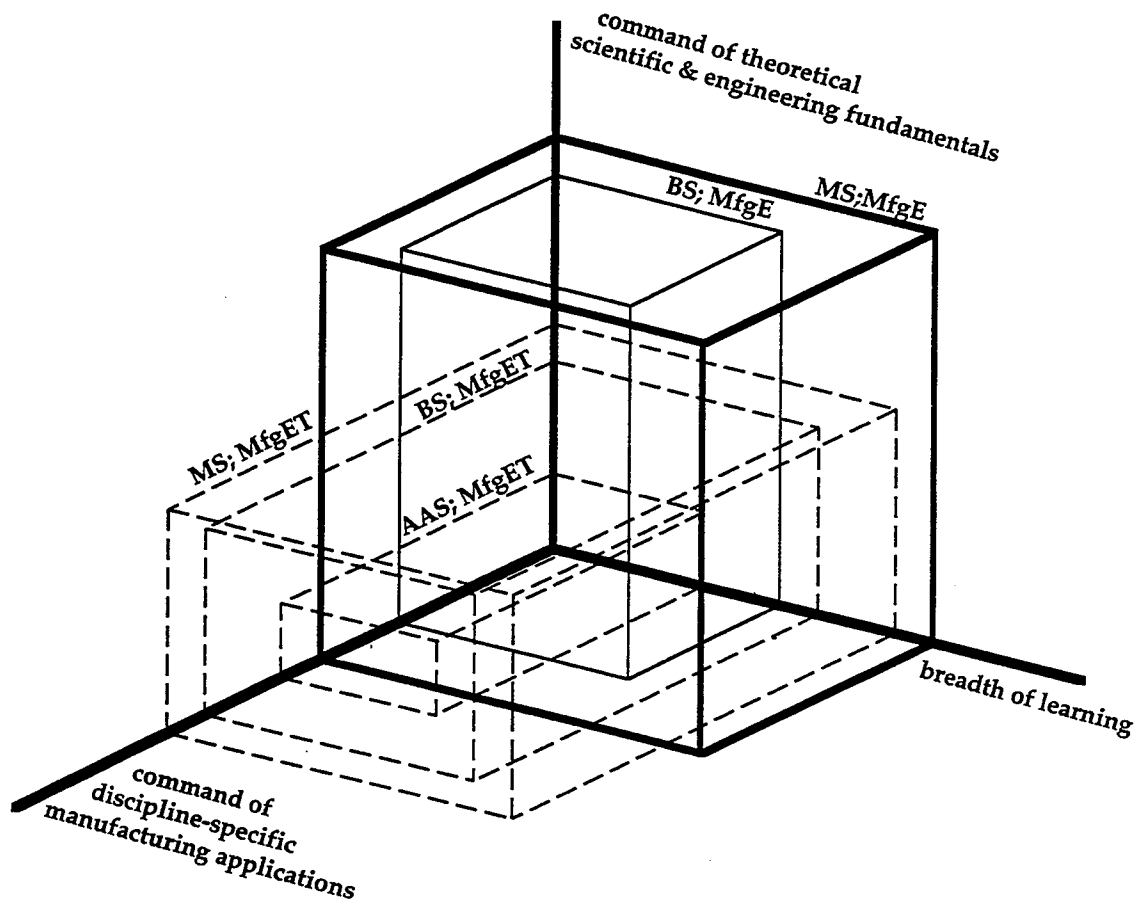


Figure 6.1: Learning Objective Coordinates for Master's Degree Programs in Manufacturing Engineering

The following features should be incorporated into all graduate program curricula in Manufacturing Engineering ...

- ... practical experience and insight into real-world manufacturing problems;
- ... team-oriented experience;
- ... evaluation of emerging manufacturing technologies for cost-effective implementation;
- ... development of a thirst for life-long learning, with the skills to access information from a variety of sources, including: libraries, technical societies, patent literature, distributed databases, professional conferences and trade shows;
- ... knowledge and understanding of the basic physical phenomena which govern manufacturing processes;
- ... the inherently random nature of human systems [including those for manufacturing] and its control;
- ... the important role of computer technology for analysis, design, modeling, control and management of manufacturing systems;
- ... a thesis or a major project -- research-oriented [for students who may continue to PhD studies] or related to industrial experience in career employment or an internship program.

Core curriculum: Programs leading to the Master of Science in Manufacturing Engineering must provide both breadth of understanding and depth of knowledge. The curricular core addresses those issues which form the underpinning of the manufacturing enterprise. A subsequent specialization provides an ability to focus on the strengths of the institution and the needs of its industrial partners.

The core of the master's degree program should reflect the essential aspects of manufacturing. The following is included to illustrate a framework for a manufacturing core ...

- **Advanced Materials/Manufacturing Processes:** Behavior of materials under processing conditions; workability; tool/workpiece interface issues; trade-offs between material and process selections.
- **Design for Manufacturing:** Considerations for assembly, processing, quality, life-cycle [including maintainability], recycling [design for disassembly]; environmental impact.
- **Production Systems Management:** Productivity; quality; cost and time management; human factors; production and inventory control; manufacturing strategies; technology change; implementation of new technology.
- **Manufacturing Systems Design and Integration:** Design of the manufacturing systems for integrated control; networking; data management; CAD/CAM/CAE/CIM integration and interfacing; architectures for organizing the physical and informational structures of the manufacturing enterprise.

Many current programs have also elected to include a course in the general core that covers the control of manufacturing processes, beyond what would be included in an undergraduate course in automatic control theory.

The core program should recognize the background and objectives of the students. In particular, detailed design of the curriculum should consider that some graduates will go directly to industry, while others will continue advanced studies.

Specialization: The graduate program in Manufacturing Engineering for each institution will be formulated by the unique capability of the institution, available physical facilities and the supporting industry. Examples of appropriate programs specialization may include one or more of the following suggestions ...

- Process Engineering and Simulation...
 - forming; casting; extruding; machining; grinding.
- Materials Science and Engineering...
 - ferrous metals; nonferrous metals; plastics; ceramics; composites.
- Automation...
 - mechanical and electronics assembly; controls; robotics; vision; process control.
- Manufacturing Systems...
 - cellular manufacturing systems; agile systems; CIM/CAD/CAM; product-process modeling; process planning; computer-assisted tool design; lean manufacturing systems; just-in-time [JIT].
- Facilities Planning and Design...
 - including materials handling
- Manufacturing Strategies and Management...
- Quality Systems...
 - total-quality-management [TQM]; planning for quality; robust design; process capability and control; variation reduction; product support and reliability.
- Design-Manufacturing Trade-Offs...
 - performance characteristics; functionality; design-for-assembly {DFA}; design-for-manufacturability [DFM]; design for maintenance; design for life-cycle cost; design for environmental impact.
- Product Liability and Safety...
 - including environmental issues.

6.5 Summary ...

Graduate programs in Manufacturing Engineering should provide participants with state-of-the-art knowledge of manufacturing and industrial systems, including the human, financial and ecological factors. It is recognized that some graduates students will go on to doctoral study, and the master's-level programs will need to provide an appropriate foundation for

further academic development. However, graduates of master's-level programs should also be able to find immediate work in industry. These two objectives are not incompatible, for graduate-level programs in Manufacturing Engineering should be demanding experiences with both theoretical and applied foundations in processes, materials and systems.

The diversity of world manufacturing -- involving such fields as electronic assembly, chemical processes, continuous-flow production and molded products -- must be provided for in graduate-level programs. Yet, each student should emerge with some specialty which embraces in-depth knowledge of a particular aspect of manufacturing.

Manufacturing is inherently interdisciplinary, often requiring expertise in related and disparate disciplines. Students are, therefore, to be encouraged to take courses in other fields to enrich their professional capacity. Graduate program curricula should make use of a variety of teaching and learning methods. Case studies, group projects, speakers from industry, laboratory experiments, co-operative learning, and a thesis or engineering project should all be included in the program of study.

Importantly, Manufacturing Engineering programs must practice what they preach with respect to quality. Students and sponsors have a right to expect that courses and other functions provided by the college or university will have the same high standards of quality that are suggested for manufacturers.