

## **AC 2007-100: ON THE STRUCTURE AND CHARACTER OF GRADUATE EDUCATION IN MANUFACTURING**

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# On the Structure and Character of Graduate Education in Manufacturing

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**Abstract:** Graduate study in manufacturing is undertaken in various guises. The Society of Manufacturing Engineers, through its Manufacturing Education and Research Community, has undertaken a focused effort to support, promote and sustain all forms of graduate study that support manufacturing industries and manufacturing engineering. The first step in this effort has been a survey of graduate programs that have self-identified as offering post-baccalaureate study in manufacturing. The first two authors are co-chair and chair of SME's Graduate Studies in Manufacturing Technical Group and have produced and circulated the initial survey. The survey and other investigation conducted by the authors seek data on demographics, size and productivity, and topical concentration of a wide variety of programs that teach manufacturing subjects. This paper will present some background history, summarize the data collected and offer some conclusions that point towards results that can be useful to any interested college, department or program.

**Historical Context:** For about the past twenty-five years, the Society of Manufacturing Engineers has sponsored and supported a wide spectrum of works in a particular vein with a consistent thread. From the early 1980's, SME has issued nearly a dozen publications whose focus has been the strengthening of the unique identity and character of college- and university-level education in manufacturing engineering and manufacturing engineering technology. Though support at the highest levels of the Society has wavered from time-to-time, a strong and vital fabric of program philosophy, learning objectives, curricular guidance and, even, model syllabi has been constructed.[1,2,3,4,5] There have, of course, been highly useful documents issued by other publishers during the past two decades.[6,7,8] However, collectively, the SME series stands as the most comprehensive body of reference work available on manufacturing education.

The majority of this work has been directed to undergraduate education. However, the Curricula 2002 workshop in 1994 produced a view of graduate-level education in manufacturing engineering and manufacturing engineering technology.[9,10] That work was the first focused attempt to articulate a comprehensive and cohesive vision for graduate studies in manufacturing and offered a general framework for orientation and content of post-baccalaureate education in the discipline. In the intervening years, however, there has been only fragmentary examination as to the extent to which a consistent approach has been adopted.

At whatever level of education, manufacturing engineering and manufacturing engineering technology remain small in the academic world -- and relative newcomers as separately-designated disciplines. A distinctive identity remains a work-in-progress. A significant portion

of the dialogue leading to the SME publications over the past quarter-century has been a struggle to articulate those features and topics and methods that uniquely characterize an educational program as ‘manufacturing’. There remains significant variation in content and, even, context. Neither the academic nor industrial communities have nucleated a consistent or complete description of the core engineering sciences and skills that make an educational curriculum uniquely ‘manufacturing’. The most succinct definition is that found in the ABET program criteria for baccalaureate programs in manufacturing engineering.[11] For graduate studies in manufacturing, the discipline remains in need of cohesion and identity. It is presumed, however, that manufacturing engineering at whatever educational level ought to maintain a consistent definition or disciplinary content. We are left with the baccalaureate criteria as the best available descriptors.

Manufacturing Engineering education should develop understanding of and proficiencies in:

- \* behavior and properties of materials as they are altered or influenced by processing in manufacture;
- \* process, assembly and product engineering;
- \* design of products and the equipment, tooling and environment necessary for their manufacture;
- \* creation of competitive advantage through manufacturing planning, strategy and control;
- \* analysis, synthesis and control of manufacturing operations using statistical and calculus-based methods, simulation and information technology;
- \* measurement of manufacturing variables and extraction of technical inferences about the process.

**Figure 1:** Proficiencies Required from Undergraduate Manufacturing Engineering and Similarly-named Programs [11]

**Manufacturing Education and Research Community:** The most recent redirection of SME has been the alignment of technical interests into ‘communities’. These are mostly recognizable as the previous ‘association’ structure recast into what is intended to be a more grass-roots member-driven collaborative. The prime exception, with no heritage in the associations of old, is a Manufacturing Education and Research Community (MER).

The communities are organized into ‘technical groups’, which are positioned as the grass-roots source of initiatives to serve member interests. Within the MER, one of the technical groups is focused on Graduate Studies in Manufacturing (GSM). The technical group was founded with the mission of promoting “... excellence in development and delivery of industry-relevant, technologically-advanced post-baccalaureate education in manufacturing engineering and technology.” This mission is to be fulfilled through five objectives:

1. identifying needs and trends in manufacturing industries;
2. illuminating developments in manufacturing science and technology;

3. identifying and describing best practices in manufacturing engineering and manufacturing engineering technology graduate education;
4. facilitating communications with and between graduate manufacturing programs, corporations, governmental organizations, and industrial, commercial and private groups interested in building manufacturing strength in the United States;
5. compiling and disseminating reports, data and other information relevant to graduate manufacturing education.

The complete GSM charter is included herein as Annex A.

**An Initial Study of Graduate Studies in Manufacturing:** As with many good engineering projects, the first step for the GSM Technical Group has been a situation audit -- an attempt to describe and, insofar as possible, to define the current state of graduate education in manufacturing engineering and technology. The opening efforts in this have been an initial study of available sources and a questionnaire.

The first stage of our study was an attempt at identifying the graduate programs that now exist in manufacturing engineering and manufacturing engineering technology. Unfortunately, the principal sources consulted yielded no consistent list of existing programs.[12,13] SME has compiled a list of 104 institutions who self-identify as offering graduate-level instruction in manufacturing engineering. The annual ASEE directory identified a different list. Another source offers yet another different population.

Furthermore, the data available in published listings are sparse, and it is not possible to extract from these sources a comprehensive or credibly accurate landscape of the state of graduate studies in manufacturing at U.S. universities. As is the rule in such data sets, all of the entries are self-identified, and each respondent uses its own criteria as to what constitutes 'studies in manufacturing'. Investigation of a sampling of university web-sites often failed to locate curricular content that could be reasonably interpreted as 'manufacturing studies'. Other examples include one or two course titles that contained the defining term. Few sites included information on enrollment or the award of degrees in 'manufacturing'. It is quite clear that there is far from universal understanding as to the meaning of this designation in terms of content or extent.

The next stage of the current study was the compilation and distribution of a comprehensive survey form. It was an attempt to collect information in some depth in five substantive categories: [a] program identification; [b] program context and content; [c] research and industry focus; [d] resources; [e] enrollment and degree production. This survey was administered through an SME web-based automated survey instrument. Announcements were sent via email to the 104 contacts who had responded to the earlier SME inquiry into schools offering graduate studies in manufacturing. These contacts, who had voluntarily identified themselves as campus leaders in graduate education in manufacturing, were invited to log onto the web-site and complete the survey during the front half of the Autumn 2006 semester.[14]

Twenty institutions completed the survey, a 19.2 percent response rate. Of these, three declared that they had no degree offerings in manufacturing (graduate or undergraduate) and offered no graduate-level courses in manufacturing. Four other respondents identified a focus or

concentration or option in manufacturing within degree programs in other disciplines (two each in mechanical engineering and in industrial engineering). Thus, thirteen respondents identified and (at least partially) defined graduate-level degree programs explicitly in ‘manufacturing’.

While the 2006 study has gathered some useful information, it is abundantly clear that a focused and comprehensive picture of graduate studies in manufacturing has not yet been attained. Available data sources are not always consistent. Much of what is available cannot be corroborated. Substantive information has been obtained from only a few of the self-identified ‘manufacturing’ schools. Nonetheless, some information can be compiled and reported.

**Landscape of Graduate Studies in Manufacturing:** A composite of information extracted from diverse sources identifies thirty-six master’s degree programs that are explicitly designated as ‘manufacturing’ somewhere in their title and could be confirmed as having students and graduates. These are offered at thirty-three universities and are identified by ten different designations. This study also searched for doctoral programs, but uncovered only four such offerings at four institutions. In addition, seven master’s degree programs have been identified, at seven schools, that offer a positively-specified manufacturing content within another degree designation. Likewise, three otherwise-designated doctoral programs containing manufacturing content have been located at two universities. In all, this study located fifty programs at forty universities that offer designated and identifiable ‘graduate studies in manufacturing’. Included are forty-three master’s degree programs at forty universities and seven doctoral programs at five institutions.

Master of Science	
Manufacturing Engineering	18
Manufacturing Systems Engineering	7
Manufacturing Systems	2
Integrated Manufacturing Systems	1
Industrial and Manufacturing Systems	1
Global Manufacturing	1
Manufacturing Leadership	1
Master of Engineering	
Manufacturing Engineering	3
Master of	
Manufacturing Systems Engineering	1
Manufacturing Management	1
Doctor of Philosophy	
Manufacturing Engineering	2
Industrial and Manufacturing Engineering	1
Computer Integrated Manufacturing	1

**Figure 2:** Graduate-level Manufacturing-designated Programs, version 1.0

Master of Science	
Engineering	1
Engineering Technology	1
Mechanical Engineering	2
Industrial Engineering	2
Engineering Management	1
Doctor of Philosophy	
Engineering	2
Materials and Nanotechnology	1

**Figure 3:** Graduate-level Manufacturing Studies in Other Programs, version 1.0

In the latest reporting year, thirty-three institutions report awarding 208 manufacturing-designated master’s degrees. Ten so-designated doctoral degree awards are reported amongst three universities. The largest quantities of graduate degrees from one program were 17 master’s and 8 doctorates, both from the same university. The highest enrollment of graduate students in manufacturing engineering (master plus doctorate) was reported as 100, in each of two universities.

**Character of Graduate Studies in Manufacturing:** Characteristics of master’s-level graduate studies in manufacturing can be inferred from the seventeen valid respondents to the GSM survey. Degrees require between 24 and 35 semester credits, with one outlier at 45 credits and a mean of 32.5 credits. Twenty-nine percent (5) of these programs are available through distance, as well as residency, means.

<u>subject</u>	<u>nr of respondents</u>
production (systems) engineering: systems theory; cell design; control systems; automation	8
manufacturing management: project management[1]; economic analysis[1]; accounting[1]	7
process engineering: design; control	5
engineered materials	5
analytical methods: statistical methods[3]; design of experiments[1]	4
product engineering	2
quality engineering	1

**Figure 4:** Required Coursework for Manufacturing Master’s Degrees  
(9 reporting)

Fifty-three percent (9) of the reported programs include required coursework for at least a portion of the degree requirements. Twenty-nine percent (5) include laboratory study attached to graduate coursework. Forty-seven percent (8) require a thesis, although only twenty-nine percent (5) of the program respondents claim that their program has a research orientation.

Research topics, as is expected, are less explicitly defined, but include the following as most frequently mentioned:

- \* product realization (product design, design for manufacturing, concurrent engineering);
- \* manufacturing processes (green manufacturing, lead-free soldering, tooling);
- \* micro-manufacturing (MEMS, self-assembly of micro-components, micro-machining);
- \* electronics/photonics manufacturing;
- \* manufacturing systems (automation, controls, information systems, RFID applications, virtual manufacturing);
- \* engineered materials.

It is interesting to note that although manufacturing management is a popular subject for instruction and a requirement in over three-quarters of the reporting schools, topics in this arena are totally absent from the mentioned research interests.

Only seven of the respondents (41 percent) indicated the means through which they maintain contact with industry. Seven (another set) reported the number of faculty dedicated to teaching manufacturing subjects. Other resources were only reported in fragment, and no useful information can be extracted. However, in response to a general question about the trend in budgetary support, fifty-two percent (9) reported a decrease over the past three years, thirty-six percent (6) reported substantive budgetary stability and twelve percent (2) reported an increase in support.

advisory board	6
student internships	6
part-time, employed students	5
adjunct faculty	5
collaborative research	5
sponsored research	4
faculty internships	0

**Figure 5:** Methods of Connecting with Industry  
(7 reporting)

While the survey respondents cannot be construed as a statistically valid reflection of the entire population of graduate manufacturing programs, it is felt that a moderately representative view has been obtained. At the least, certain characteristics of graduate manufacturing engineering programs begin to emerge. Perhaps more tellingly, what is not said in the survey and its supporting investigation provides some guidance for future examination.

	<u>range</u>	<u>mean</u>
full-time faculty	1 to 20	6.6
total faculty	2 to 26	10.4
FTE faculty	2 to 20.5	7.2

**Figure 6:** Faculty Dedicated to Teaching Manufacturing Subjects  
(7 reporting)

**Commentary:** The 2006 GSM survey included a section that invited open-ended comments about various issues of importance to the respondents. The comments offered fall into three general categories: students; image and resources; support from SME.

**Students:** There appear to be rather general concerns over the available pool of qualified and interested graduate students, especially those trained in domestic institutions. Comments were offered suggesting problems in both quality and quantity.

Suggestions for increasing the attractiveness of graduate study in manufacturing included ... strengthening undergraduate enrollments as a pipeline matter; public and very visible moral support from visionary leaders in manufacturing industries; increasing emphasis on product design and innovation; vigorous embrace of new topics in micro-, nano- and/or bio-manufacturing; stress on materials and systems aspects of manufacturing; better funding for assistantships and laboratories; expanded delivery by distance learning.

These comments recall the survey responses about maintaining connections with industry (see Figure 5). Perhaps there is a correlation between the small fraction of respondents who report any method of connecting with industry and the overall difficulty in recruiting students. The institutions reporting an active industry interaction and /or research program tended to be those with the strongest enrollments.

**Image and Resources:** These two issues are intertwined. Schools that indicated declining resources also cited the need to educate administrators at university and state levels about the unique disciplinary identity of manufacturing engineering and its value to regional and national economic well-being.

There were several comments about the difference between the somewhat traditionally narrow public view of manufacturing and the reality of modern manufacturing engineering as technically innovative, multi-faceted and pervasive throughout the supply-production-distribution system of wealth creation. In this regard, perceptions of the general public, and indeed of many engineers in industry and academia, have not kept pace with the strong shifting of manufacturing studies from traditional metalworking to also embrace broader processing for biotechnology, electronics and other emerging fields.

**Support from SME:** The principal professional society for manufacturing engineers is seen as a focal point for providing leadership in addressing the problems besetting the discipline's educational foundations. The consensus of the comments received recommend that SME should be focused on dramatic image enhancement -- telling the exciting story of manufacturing technologies and product realization that is waiting to be told. And telling the story effectively to educational administrators, government leaders at all levels and to SME's corporate members. It was suggested that SME flagship publications are underselling the discipline by not adequately portraying the richness, breadth and excitement of manufacturing engineering, as well as its crucial importance to the long-term economic strength of the nation.

There were also comments indicating that SME should provide curricular guidance for graduate, as well as undergraduate, manufacturing education. The general tenor of the comments received suggests that such guidance ought to encompass substantially enlarged technological breadth than has been the traditional SME scope -- to include topics in advanced materials, product realization, macro-economic influences of manufacturing and new fundamental technologies.

**Next Steps:** A few key conclusions can be extracted from the brief study reported in this paper. The authors believe that the following are the critical conclusions:

1. The task of gathering meaningfully comprehensive data for graduate-level programs in manufacturing engineering and manufacturing engineering technology, as well as for manufacturing studies in related disciplines, is somewhat formidable. Available databases are inadequate. The survey method garners response from only a fraction of the relevant population. The fundamental research necessary to compile fully authoritative information is beyond the reach of volunteer effort or of the funding support of a few individual faculty. A significant funded effort is needed. The SME Education Foundation and/or the National Science Foundation and/or other agencies focused on the nation's manufacturing well-being should establish a funded program(s) to create and maintain a comprehensive database of graduate study in manufacturing.
2. There do not appear to be any consistent definition or commonly held descriptors for graduate-level manufacturing engineering programs. A standard, or common set of descriptors, should be created for the discipline. The descriptions that are displayed in the 1994 report and in the current program criteria for undergraduate manufacturing program accreditation, together, comprise a valid launching point for creating a common and comprehensive definition.
3. Internal program review could be an important tool in developing and strengthening graduate programs in manufacturing engineering and manufacturing engineering technology. There does not appear to be a consistent sense of purpose for graduate programs in manufacturing. A template for use by local programs in reviewing their continuing alignment to their purpose and mission would be of significant value and should be created. Such a tool should aid in assessing program relevance and currency from the perspectives of students, alumni, adjunct faculty and industry advisors.

4. A broadly-accepted recognition of graduate programs in manufacturing is needed to increase their appeal and value. The utility of extending an ABET accreditation to graduate-level programs should be examined. In particular, this examination should seek evidence of the perceived value of accreditation in the ranks of government and industry, as well as in academia, and especially on whether such perceptions for the bachelor's level accreditation might extend to the advanced level.

While not all of these issues are within the charter of the GSM Technical Group, all are valid agenda items for the MER Community. There is also a clearly indicated role for the SME Accreditation Committee that should be addressed by that group. The immediate next steps for the GSM Tech Group would seem to be the following:

- \* continue to develop the baseline of description and definition of the current state of graduate studies in manufacturing;
- \* articulate suggested agenda items for sister technical groups, both within the MER Community and elsewhere, that will foster the cause of graduate studies in manufacturing;
- \* develop priorities for additional initiatives in support of graduate studies in manufacturing;
- \* formulate processes through which to create information products that serve the interests of graduate educators in manufacturing.

As with any volunteer organization, the degree of success in these measures is directly dependent on the quantity and quality of participation. The GSM Technical Group is anxious to include as many new faces as are interested in the tasks ahead. Check in via the GSM web site by following the education/MER buttons through from the SME home page, or contact one of the authors of this paper.

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## **Annex A: Charter of SME's Graduate Studies in Manufacturing Technical Group**

### **Graduate Studies in Manufacturing Technical Group *Manufacturing Education and Research Community Society of Manufacturing Engineers***

**Mission:** The Graduate Studies in Manufacturing (GSM) Technical Group of the Manufacturing Education and Research Community exists to foster excellence in development and delivery of industry-relevant, technologically-advanced post-baccalaureate education in manufacturing engineering and technology.

**Objectives:** The Graduate Studies in Manufacturing Technical Group will fulfill its mission through the following:

1. identifying needs and trends in manufacturing industries;
2. illuminating developments in manufacturing science and technology;
3. identifying and describing best practices in manufacturing engineering and manufacturing engineering technology graduate education;
4. facilitating communications with and between graduate manufacturing programs, corporations, governmental organizations, and industrial, commercial and private groups interested in building manufacturing strength in the United States;
5. compiling and disseminating reports, data and other information relevant to graduate manufacturing education.

**Activities:** The Graduate Studies in Manufacturing Technical Group will undertake fulfillment of its objectives and mission through activities that embrace the widest possible constituency of people interested in graduate education in manufacturing. Among these activities will be:

1. recruit and maintain a Steering Committee to lead the work of the Group.
2. develop and sustain working groups to organize and undertake efforts to fulfill the five objectives of the Group.
3. create, activate and maintain procedures for assembling, summarizing and disseminating needs and trends in manufacturing industries. (Objective 1)
4. create, activate and maintain procedures for compiling and disseminating emerging and developing manufacturing sciences and technologies. (Objective 2)
5. assemble, maintain and disseminate a directory of graduate manufacturing education programs, faculty and leaders. (Objective 3)
6. develop, maintain and disseminate a compendium of best-practices in graduate manufacturing education. (Objective 3)
7. identify and collaborate with other domestic and global organizations with compatible goals. (Objective 4)
8. develop and deliver an effective series of communications products to, for and between constituencies concerned with and/or interested in the pursuit of excellence in graduate manufacturing education. (Objective 5)

#### **Operating Guidelines:**

- \* Membership in the Steering Committee should be small, somewhere in the mid-single digits.
- \* The Steering Committee membership should be drawn from academia, industry and government.
- \* Each of the working groups should be lead by and be the responsibility of one member of the Steering Committee.
- \* Working groups (tentative):
  - Manufacturing Technologies and Practices (Objectives 1, 2 and 5)
  - Graduate Manufacturing Programs and Leaders (Objectives 3 and 5)
  - Collaborations in Graduate Manufacturing (Objectives 4 and 5)
- \* Working groups are semi-autonomous and are tasked to establish action plans for developing and disseminating explicit products, with priorities, detailed definition and timelines determined by the working groups.

#### **Initial Practice:**

- \* Founding members of the Steering Committee are:
  - Ronald J. Bennett; University of St. Thomas
  - Jun Ni; University of Michigan
  - Yiming Rong; Worcester Institute of Technology
  - David L. Wells; North Dakota State University

**Annex B: Valid Responses to the GSM 2006 Survey of Graduate-level Education in Manufacturing**

The authors extend grateful thanks to the manufacturing leaders at the seventeen institutions that provided valid to the 2006 survey instrument. Those institutions are:

Boston University  
Brigham Young University  
University of California-Berkeley  
Central Connecticut State University  
Cleveland State University  
Grand Valley State University  
University of Kentucky  
Lehigh University  
Michigan Technological University  
New Mexico State University  
North Dakota State University  
Robert Morris University  
University of St. Thomas  
University of Southern California  
University of Texas-El Paso  
Worcester Polytechnic Institute  
Youngstown State University