AC 2012-4210: THE FOUR PILLARS OF MANUFACTURING ENGINEERING: WHAT ENGINEERING AND TECHNOLOGY GRADUATES SHOULD KNOW ABOUT MANUFACTURING

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THE FOUR PILLARS OF MANUFACTURING ENGINEERING: WHAT ENGINEERING AND TECHNOLOGY GRADUATES SHOULD KNOW ABOUT MANUFACTURING

Abstract

The ***Four Pillars of Manufacturing Engineering*** essentially differentiates the unique character of the manufacturing, manufacturing engineering and manufacturing engineering technology disciplines. It defines the standard for advanced manufacturing topics, and provides a body of knowledge concept with which all those engaged in advanced manufacturing education can align. Developed by the Society of Manufacturing Engineers (SME) through its Center for Education, the four pillars model is derived from the ABET accreditation criteria for manufacturing engineering programs and builds on the topics in the SME body of knowledge for the certification of manufacturing engineers and manufacturing technologists. The concept of the four pillars encompasses: 1) Materials and manufacturing processes; 2) Product, tooling, and assembly engineering; 3) Manufacturing systems and operations; and 4) Manufacturing competitiveness.

The ***Four Pillars of Manufacturing Engineering*** is a tool for promoting greater understanding of the breadth and depth of the field of manufacturing engineering. Initiatives are underway, led by the SME Center for Education, to build on this foundation, to promulgate the concept broadly within SME, and to engage in dialog with other professional societies that represent engineering, engineering technology, industrial technology, and related educational programs from whose graduates enter manufacturing-related career paths. Supporting materials are to be developed to aid in helping to inform a broader array of manufacturing professionals, post-secondary educators, high school educators, public policy officials, media representatives, governmental agencies, and the general public about the manufacturing engineering field. This paper will provide a status report on these efforts, demonstrate how the Four Pillars may be used by various audiences to position their organizations and initiatives, and outline additional plans for future implementation.

1. Overview of the Four Pillars Concept

The concept of The Four Pillars of Manufacturing Engineering was developed from the program criteria for accreditation of manufacturing engineering and similarly named programs as promulgated by ABET Inc, the recognized accreditor for college and university programs in applied science, computing, engineering, and technology worldwide. The philosophical underpinning is that *Manufacturing requires that a modification of the shape, form, or properties of a material takes place in a way that adds value*.[1] The Four Pillars and the intent of the accreditation criteria are presented below:

- Materials and manufacturing processes: understanding the behavior and properties of materials as they are altered and influenced by processing in manufacturing
- Product, tooling, and assembly engineering: understanding the design of products and the equipment, tooling, and environment necessary for their manufacture
- Manufacturing systems and operations: understanding the creation of competitive advantage through manufacturing planning, strategy, and control

- Manufacturing competitiveness: understanding the analysis, synthesis, and control of manufacturing operations using statistical and calculus based methods, simulation and information technology

Additional detail used to define the programmatic content of such programs is provided by the Body of Knowledge developed with industry by the Society of Manufacturing Engineers for its certification programs for manufacturing engineers and technologists.[2]

Graphic Representation of Four Pillars Concept To help communicate the Four Pillars concept and the attendant details to a wide range of people and organizations, a graphic representation was developed using the metaphor of a building whose roof structure is supported by four pillars that rest on a foundation (Figure 1).

The foundation shows the educational fundamentals on which the manufacturing engineering field is based, including mathematics and science, communications, and the many aspects of personal effectiveness.

The four pillars are capped with the titles shown above for the four major competencies expected of manufacturing engineers and technologists. Within the four pillars, ten major subject areas are arrayed to give more detail to the content included in baccalaureate degree programs: Engineering Sciences, Materials, Manufacturing Processes, Product Design, Process Design, Equipment/Tool Design, Production System Design, Automated Systems and Control, Quality and Continuous Improvement, and Manufacturing Management. The roof structure emphasizes that laboratory experiences, quality, continuous improvement, and problem analysis pervade the manufacturing engineering field and integrate its various facets.

Below the building foundation are more detailed lists of the Four Pillars subjects. These make up the content of the programs. This list constitutes the basis for SME certification exams for Certified Manufacturing Engineer and Certified Manufacturing Technologist.

2. The Four Pillars and the SME Center for Education

The Four Pillars of Manufacturing Engineering is a tool for promoting greater understanding of the breadth and depth of the field of manufacturing engineering. The role of the SME Center for Education is to build on this foundation, to promulgate the concept broadly within SME, and to engage in dialog with other professional societies that represent engineering, engineering technology, industrial technology, and related educational programs from whose graduates enter manufacturing-related career paths. The Four Pillars of Manufacturing Engineering also may be used by industry to identify training and education needs of its workforce and as a means of providing input to educational institutions that serve as a source for employees. Additionally, the role of the SME Center for Education is to communicate the importance, value and characteristics of advanced manufacturing and fulfill SME's role in higher education by successfully achieving broader participation in and use of the Four Pillars of Manufacturing Engineering and information gained from the comprehensive study of manufacturing education called *Curricula 2015 – A Four Year Strategic Plan for Manufacturing Education.*

The term 'manufacturing' conjures up varying images for different audiences. It is a goal of SME to change this to a common, accurate, and positive image through a society-wide branding initiative. In alignment with that goal, the Four Pillars of Manufacturing Engineering model defines the design, production, technology and engineering aspects of 'advanced

manufacturing' in broad yet specific terms. It has long been known in the business community that establishing a 'standard' is essential to the growth of a technology and of the industries that participate in that technology. The Four Pillars of Manufacturing Engineering defines the standard for advanced manufacturing topics, and provides a body of knowledge concept with which all those engaged in advanced manufacturing education can align.

The image of manufacturing needs updating to reflect the wealth of opportunities available, the critical role that domestic manufacturing plays in our economy, the skills needed, the 'clean' nature of modern advanced manufacturing operations, the significant benefits that manufacturing provides to society and the exciting new applications of manufacturing. It must also be articulated in a way with messages that resonate with the desired audiences. For example, advanced manufacturing is in a constant state of change. Who would have imagined just a decade ago that building scaffolding for human organs would be an additive manufacturing process? Content of curricula must continuously be updated, disseminating research and new practices in manufacturing like the example above.

With respect to higher education, the Four Pillars of Manufacturing Engineering provides a clear guide for manufacturing education programs in manufacturing engineering and manufacturing engineering technology regarding topics that need to be addressed to meet the needs of advanced manufacturing enterprises. Currently the manufacturing engineering specific criteria for the Engineering Accreditation Commission (EAC) of ABET Inc. are precisely aligned with the Four Pillars, and similar work is currently underway to revise the Technology Accreditation Commission (TAC) of ABET Inc. criteria for manufacturing engineering technology programs. Similar work is being done by The Association of Technology, Management, and Applied Engineering (ATMAE) for its accredited programs. (See details in Section 6 of this paper.)

Wide scale implementation of the Four Pillars concept among manufacturing programs will require consistent communication with the department chairs and curricula committees of manufacturing and other programs that offer manufacturing courses. In keeping with the charge to the SME Center for Education, appropriate communication methods are being developed to achieve broad dissemination and understanding of the Four Pillars, and the resources available to assist programs in updating their curriculum. The SME Center for Education is planning a series of webinars for chairs and faculty members of these programs to further the understanding and use of the Four Pillars model.

In addition, the Center for Education is reaching out to other professional organizations. For example, in March 2012 the Center was invited to present a briefing on the Manufacturing Engineering Body of Knowledge to the American Society of Mechanical Engineers' International Mechanical Engineering Education Conference to begin a dialogue with that organization and its members, and plans to offer similar outreach to other professional societies.

3. The Four Pillars and *Curricula 2015*

The development of the Four Pillars concept was completed in parallel with the comprehensive SME study of manufacturing education called *Curricula 2015*. Over a period from 2008 to 2011 the manufacturing community met multiple times to discuss the past, current, and future state of manufacturing education. Some major topics included industry needs, student recruiting, manufacturing programs, globalization, and the evolving curricula. In the past manufacturing curricula were housed in other programs, such as mechanical or industrial engineering. Manufacturing options have been growing inside other programs, but also as stand-

alone manufacturing programs. The manufacturing knowledgebase in industry was often customized to each company. The mixture of understandings and definitions became obvious in most technical discussions. A frequent topic for discussion was, "what should be in a manufacturing program?" What is fundamental and core knowledge; or specialized, industry specific, and professional skills? The different terminology, definitions, and expectations complicated the discussion and planning efforts. There was a clear need for a common model for manufacturing curriculum that was satisfied by the Four Pillars of Manufacturing Engineering. A report was prepared from the results of the *Curricula 2015* initiative.[3]

Extensive discussion of the relationships between the Four Pillars and the much broader issues and observations addressed during the *Curricula 2015* initiative are listed here.

- Future use of the Four Pillars of Manufacturing Engineering should be guided by the SME Center for Education. [See Section 2 of this paper.]
- The Four Pillars should be used to ensure that there is a common understanding of the manufacturing engineering field.
- The Four Pillars should be promulgated by ongoing dialogs with designers of Engineering and Engineering Technology curricula in manufacturing-named programs and with designers of curricula in other disciplines whose graduates often work in Manufacturing Engineering functions of product-producing industries. This will ensure that graduates obtain knowledge and skills in critical manufacturing principles and practices.
- The current version of the Four Pillars (as shown in Figure 1) is only the beginning of the process to more completely define the field of manufacturing engineering. Additional documentation needed to enhance the utility of the Four Pillars can be produced by creating working groups for each of the pillars, enabling individual developers to create new materials, and disseminating the resulting materials. Champions should be identified for each major part of the Four Pillars.
- Employers of professionals and technicians in the manufacturing functions of product-producing industries should use the Four Pillars to assess the adequacy of prospective employees to perform those functions and to design in-house training and education programs to enhance the skills and knowledge of critical personnel.
- The hiring of graduates from manufacturing-named engineering and engineering technology programs should be promoted to fulfill the primary manufacturing engineering functions as key members of teams that may also include graduates from other disciplines.
- The concept of the Four Pillars should be used to encourage and guide manufacturing and production engineering programs to seek ABET accreditation.

4. The Four Pillars and the SME MER Community

The members of the Manufacturing Education and Research (MER) Community played a complementary role in creating the Four Pillars concept. However, their earlier work during the *Curricula 2015* initiative was instrumental in identifying the need for and the development of the Four Pillars concept. *Curricula 2015* considers manufacturing education from the point of view of the past, present and the future of the manufacturing profession. Throughout the process members have made recommendations to shape the future of manufacturing education.

As SME-MER members assist in the implementation of the Four Pillars concept, they will undertake the following steps:

1. Translate the recommendations from the *Curricula 2015* initiative into action items.
2. Help develop a roadmap for manufacturing technology. It will identify strategic areas to focus on, and project the timeline in which the evolving technologies will be in place. The exercise will help develop a long term strategy for manufacturing engineering education.
3. Help develop an understanding of the global manufacturing industry. The result will specify the status of the global industry and where it is headed. It will also outline the implications for manufacturing and manufacturing education in the USA.
4. Develop a profile of the skills needed in the manufacturing industry, especially for future competitiveness in the global context.
5. Help develop the manufacturing curricula. This should happen in association with the SME Accreditation Committee. As part of the process, existing curricula must be reviewed and revised and new curricula should be proposed.
6. Create mechanisms to develop the faculty and meet the needs of the manufacturing education programs.
7. Develop a recruitment process that will help develop a continuous supply of well prepared students coming in to the manufacturing programs.
8. Support SME's Center for Manufacturing, the Accreditation Committee, and the North American Manufacturing Research Institute (NAMRI) in their efforts to promote and strengthen manufacturing engineering education.
9. Work with the Center for Manufacturing and promote the Four Pillars concept to strengthen manufacturing education.
10. Help efforts to develop policies that will impact manufacturing and manufacturing education.

The steering committee of the MER Community recommends that manufacturing faculty members, program coordinators, and department chairs consider the following:

- Use the Four Pillars in curriculum development activities by mapping their curricula to the detailed set of topics listed there.
- Communicate the Four Pillars concept to their Industrial Advisory Committee members and employers of their graduates. This will be an important, locally-focused means of disseminating the Four Pillars as a consistent representation of the manufacturing engineering field.
- Use the Four Pillars during self-assessment exercises in preparation for visits by ABET program evaluators.
- Become champions for parts of the Four Pillars within their special areas of interest and research to develop supporting materials that can be used broadly by other programs.
- Use the Four Pillars when communicating the nature of their programs to university administrators, colleagues in other disciplines, prospective employers, current and prospective students, media representatives, and the general public.

5. Role of the NCME in Promoting and Developing the Four Pillars Concept

The NSF-sponsored National Center for Manufacturing Education (NCME) was established in 1995 to promote and enhance the effectiveness of manufacturing education broadly with particular emphasis on community colleges. Developed as a partnership between Sinclair Community College and the University of Dayton, the NCME has become known as a national resource serving the broad array of manufacturing and engineering technology programs and for a wide spectrum of manufacturing-related engineering programs. Early efforts were mainly directed to the development of novel curriculum materials for an associate degree program in manufacturing engineering technology. Later efforts led to the implementation of a popular clearinghouse for high-quality educational materials called METEC – Manufacturing and Engineering Technologies Education Clearinghouse [**www.METEConline.org**]. METEC serves as the primary education clearinghouse for the SME Manufacturing Education & Research Community and the ASEE Manufacturing Division.

An important Internet-based initiative, called ***careerME.org***, is directed to young people to enhance the awareness of the manufacturing engineering field and other STEM-related career paths. With partial funding by the SME Education Foundation, ***careerME.org*** has been expanding to nationwide impact through collaborations with many related organizations such as Project Lead The Way (PLTW) and the Manufacturing Institute of the National Association of Manufacturers.

With these accomplishments and established relationships as a backdrop, plans are underway for the NCME to assist SME in the development of materials to more clearly define the Four Pillars concept and to disseminate the resulting products through METEC, ***careerME.org***, PLTW, and other professional societies. Using a module development process derived from earlier instructional materials development activities, and adding current Internet WEB 2.0 technologies, the NCME can develop flexible, technologically sound materials useful to curriculum designers from a wide array of educational programs from middle and high school through BS degree levels.

As an affiliate for PLTW the NCME will provide guidance and support to exemplary schools identified as PRIME (Partnership Response in Manufacturing Education) schools by the SME Education Foundation. These schools already have exemplary manufacturing curriculum, skilled and dedicated instructors, engaged and active students and connectivity to the local manufacturing base or an SME membership group. The NCME will help these schools in integrating the Four Pillars concept more completely into their programs. Additionally, a methodology for categorizing current materials and determining the need for new educational materials using the ***Four Pillars of Manufacturing Engineering*** framework will be developed and utilized.

6. Use of the Four Pillars by ATMAE and their Manufacturing-related Programs

The Four Pillars concept and document has a very substantial potential as a resource for the numerous academic programs that are accredited by the Association of Technology, Management, and Applied Engineering (ATMAE). This organization sets standards for academic program accreditation, personal certification, and professional development for educators and industry professionals involved in solving complex technological problems and integrating technology, leadership and design.

The ATMAE accreditation is recognized by the Council for Higher Education Accreditation also known as CHEA and holds the same acknowledgment that is given to the

Accreditation Board of Engineering and Technology (ABET). The ATMAE Scope of Recognition covers associate, baccalaureate, and master's degree programs in technology, applied technology, engineering technology, and technology-related disciplines delivered by national or regional accredited institutions in the United States.

The many manufacturing-related programs accredited by ATMAE have content and emphases that are tailored to a wide range of industry needs and, with the increasing industry demands for technically-astute, team-oriented employees in their skill mix, are an essential complement to engineering and business degree programs. Graduates traditionally have a very strong applied base of knowledge that includes extensive hands-on laboratory experiences, and with an orientation much closer to the "shop floor" in regard to technologies and/or planning, support, and guidance of production. ATMAE divisions and focus groups include, among others, Manufacturing, Industry, and Management Divisions and cover technical focuses such as nanotechnology, electronics, and safety.

The Four Pillars will provide these academic and professional focus groups with a structured, comprehensive source from which to plan and assess at all levels and in a variety of settings. There are several specific ways in which the Four Pillars may be utilized by ATMAE and its constituents:

- Academic departments may use the graphic depiction to communicate, within the overall context, existing program scope to administrators, potential students, hiring industry, accreditation review teams, and other interested parties.
- Academic departments may also use the Four Pillars as a tool for identifying needs in regard to continuous improvement of existing programs and new directions, especially during dialogue with their external advisory committees.
- Faculty may use the Four Pillars as a reference in defining, prioritizing, adding and gleaning specific course content.

For any of the above applications, individuals and groups may delineate the specifics of their programs or courses as subtopics within the higher-level Four Pillars outline. The Four Pillars were presented and discussed in a forum at the November 2011 annual conference of ATMAE, and it is anticipated that ATMAE will formally recognize the Four Pillars as an important reference by its manufacturing-related members.

7. Communicating with Related Professional Societies about the Four Pillars

The SME Center for Education has been charged with implementing recommendations from *The Role of SME in Higher Education* Report.[4] Emphasis is placed on alignment of actions within SME, between SME and current partners, and beyond to other organizations with similar goals to increase manufacturing competitiveness. There is a need to establish and support robust communications among all stakeholders, from K-12 education through post-secondary education to industry, and among the professional and government organizations whose responsibility it is to strengthen the manufacturing sector and manufacturing education that supports it. An obvious necessary requirement to achieve alignment and communication is to build alliances among all of these entities.

As a standalone discipline, manufacturing engineering is relatively young with only one program being accredited in the 1970's, 5 programs being accredited in the 1980's, and 8 programs each being accredited in the 1990's and following the year 2000. A similar breakdown

exists for manufacturing engineering technology programs. The number of academic programs in manufacturing engineering and manufacturing engineering technology is limited in the United States. Many who are employed in manufacturing engineering and technology positions in industry have been educated in other disciplines, such as mechanical engineering, industrial engineering and industrial technology. Reports from employers indicate that many of these individuals, who do have excellent technical skills in general, are lacking in knowledge of key manufacturing concepts, particularly the integration of the design, materials processing, product fabrication and assembly system. While the manufacturing engineering discipline provides all of the necessary background and preparation for an engineer to be an effective practitioner of the profession, many institutions are interested in selectively incorporating manufacturing content required of their graduates and demanded by their constituencies into existing programs. Consequently, a major goal of the Center for Education is to reach out and work with these non-manufacturing titled programs to help build essential manufacturing concepts into their curricula for the benefit of the programs, their students and eventual employers. The Four Pillars of Manufacturing Engineering provides a strong, clear conceptual model for the topics that are needed in those curricula as well.

Why is SME the central player in this initiative? It is because SME holds the key manufacturing knowledge and has the technical expertise within the organization's functional units, and in its membership and volunteers, which is needed to integrate and accomplish these goals. SME is already recognized as the 'go to' organization for advanced manufacturing knowledge and practice, but it is significant that it is not as fully recognized for that role as it needs to be. To paraphrase Mahatma Gandhi, "*SME must be the change we want to see*." If not SME, who? If not now, when? To delay would be to lose opportunity and time, to abandon our responsibility to others who do not have the same core knowledge of manufacturing as SME, and most importantly; we would exacerbate the lost competitive advantage for manufacturing industries in North America. SME is simply the most obvious entity to drive the changes needed and carry out the integration and completion of many of these actions.

The SME Center for Education is positioned to bring SME and other professional societies and associations together to determine the best methods to ensure that their programs include critical content from the Four Pillars of Manufacturing Engineering. SME staff has many interfaces that touch these issues and it will be important that both the volunteer portions of accomplishing these efforts be aligned with staff efforts. The details for accomplishing that coordination are not defined here, but the need is clear.

Some specific actions that the SME Center for Education is focusing on are:

- Implement a communications plan of regular communications with engineering and technology department heads and manufacturing program leaders and faculty that: executes informative and interactive exchanges of information and ideas at least quarterly electronically and via web and live meetings; aligns with and integrates with other SME communications; identifies trends, needs of educators, etc.
- Monitor and report on trends in education and industry needs and determine recommendations. Gather data on real needs of manufacturers, effectiveness of pre-engineering programs and needs of education programs to become accredited.

- Identify schools developing manufacturing programs and options that could become accredited and align them with SME resources and support. Especially encourage two-year manufacturing programs to become accredited.
- Partner with other organizations with interests in manufacturing (NAM, ASME, IIE, IEEE) to advocate integration of manufacturing curriculum in other technical and engineering and business and management program areas. Use variations of the Four Pillars of Manufacturing Engineering as resources.
- Support approaches to incorporate manufacturing certification into manufacturing engineering and technology programs.
- Support creation of manufacturing education modules that exemplify best practices.
- Widely communicate the Four Pillars of Manufacturing Engineering model to all stakeholders to demonstrate the revised definition of advanced manufacturing.
- Work with the American Society of Mechanical Engineers (ASME) to support inclusion of some manufacturing curricula into mechanical engineering programs, particularly to strengthen the design/build component, to address the gap between design and manufacturing that they have determined exists in the knowledge of mechanical engineering program graduates.
- Work with the Institute of Industrial Engineers (IIE) to encourage international manufacturing/production academic programs to seek accreditation. Communicate with schools to offer help in developing accreditable programs and to seek accreditation.
- Develop relationships with other organizations, such as IEEE, ABET and ASEE and identify other venues to disseminate career and curriculum models and resources for manufacturing technology and engineering education programs.
- Work with accreditation agencies including ABET and ATMAE, to ensure that criteria relevant to manufacturing are addressed that reflect competencies required by industry for advanced manufacturing.

8. Conclusion

This paper describes the value and current state of promulgating the Four Pillars of Manufacturing model to a wide variety of constituencies.

The Four Pillars concept and the need for continuous improvement of manufacturing education are not static and ongoing efforts are needed, such as:

- Keep manufacturing education models current with new technologies, practices, etc. and update continuously.
- Establish responsibility for maintaining an ongoing process to update manufacturing education topics for content as they emerge
- Continuously improve post-secondary manufacturing education through communications of advancements and updates to the Four Pillars of Manufacturing Engineering to the following types of programs:

- Two-year community and technical college programs that provide technically trained 'middle skilled' people to run advanced manufacturing operations. Encourage these programs to explore accreditation as a means of raising their perceived value.
- Four-year technology and engineering programs that educate graduates who have the skills to optimize the design and materials processing systems, and the production systems, continuous improvement and leadership elements that are part of the Four Pillars model.
- Incorporate the Four Pillars of Manufacturing Engineering body of knowledge topics into non-manufacturing programs so graduates understand the design/build process and implications.
- Continue to build relationships and interactions with other disciplines.

All who have a stake in enhancing the future of manufacturing education are called to action to promulgate the use of the Four Pillars as a means to help foster a greater understanding of manufacturing, improve the image of manufacturing, prompt review of curricula in named manufacturing programs or in other disciplines to enhance their preparation of engineers and technologists who are going to become employed in manufacturing enterprises.

Recent national publicity on this issue is promising as indicated in the February 2012 report, *A National Strategic Plan for Advanced Manufacturing* developed by the National Science and Technology Council, part of the Executive Office of the President.[5] This report represents a national strategic plan with five areas of recommendations. It is an *innovation policy*, not an industrial policy, having cross-cutting breadth of application with the federal role to support infrastructure for partnership building to move ideas from research to high levels of technical readiness. A related group, called the Advanced Manufacturing Partnership (AMP), [http://www.manufacturing.gov/amp.asp] represents the private sector perspective on manufacturing. These and other such national initiatives indicate that manufacturing is getting a significant amount of positive attention, creating expectations of resources and support for innovation that includes *both product design and manufacturing* that will have an impact on manufacturing education and research.

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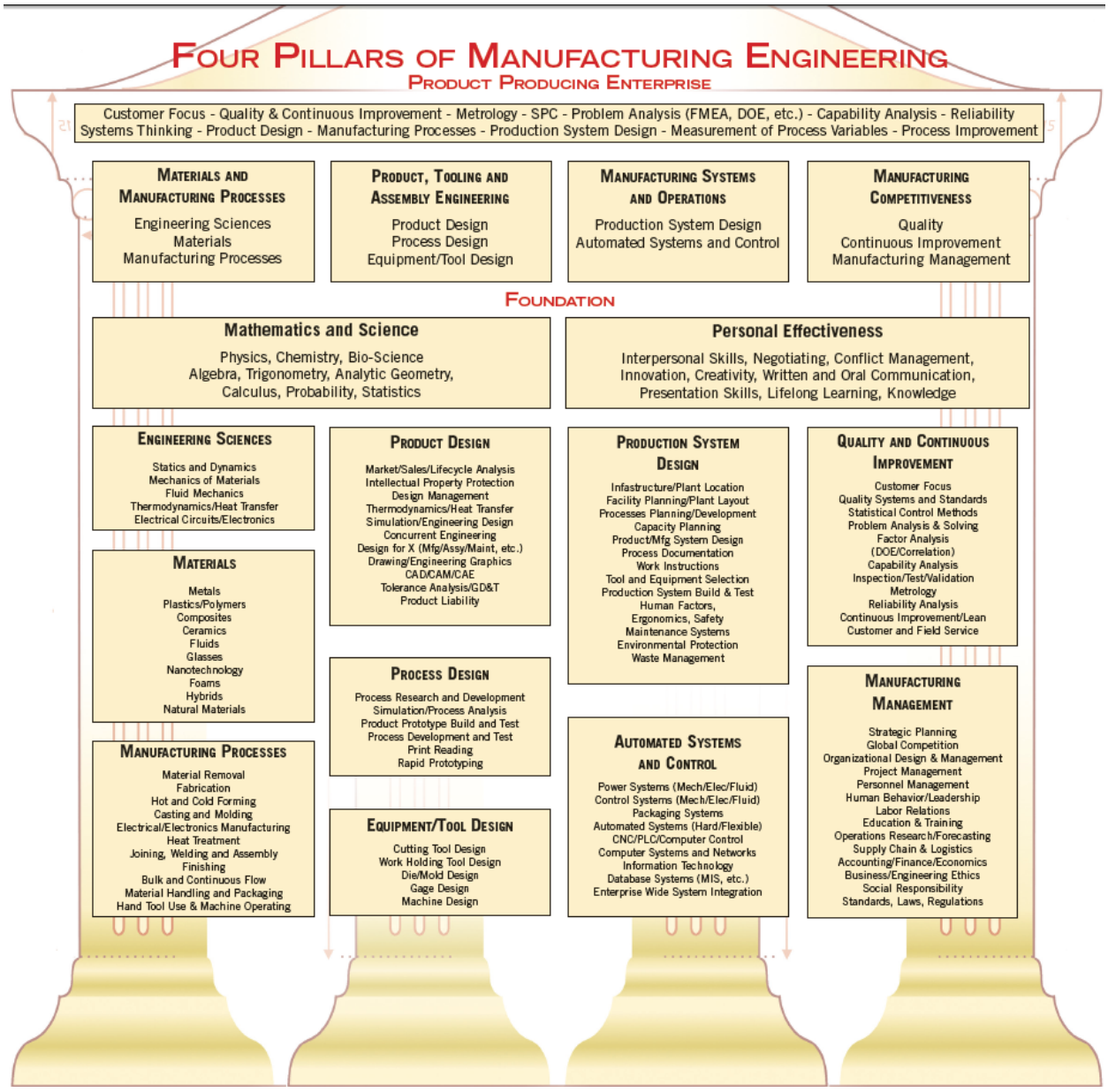

Figure 1 Graphic Representation of the Four Pillars of Manufacturing Engineering
[Available for download at www.sme.org/mer-resources]