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Educating the Manufacturing Engineer of the Future

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Educating the Manufacturing Engineer of the Future

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Abstract
Currently very limited number of colleges offer accredited undergraduate degrees in manufacturing engineering in the U.S. and the rest of the world even though there has been a great need for and demand of manufacturing engineers. It is an extremely hands-on and cross-disciplinary field that is almost unlimited in its applications, varying from heavy manufacturing to food processing or electronics, from medical devices to toys or textiles.

According to the fairly recent wisdom of "Four Pillars of Manufacturing Engineering of a Product Producing Enterprise" developed by the Society of Manufacturing Engineers (SME), manufacturing engineers need to be prepared and competent in four thrust areas: (i) materials and manufacturing processes, (ii) product, tooling, and assembly engineering, (iii) manufacturing systems and operations, and (iv) manufacturing competitiveness. In addition, a good manufacturing engineering curriculum has to have to a strong foundation in mathematical and science preparation, and personal effectiveness and development content towards valuable soft skills. This paper studies the recent evolution of manufacturing engineering curriculum and state of these programs in the U.S. along with employment statistics. Advantages and disadvantages of offering such a degree is also included in this paper, explaining the facts of why colleges avoid offering such a degree, and why these programs are not popular with students entering engineering study. The paper is concluded with the future of the manufacturing engineering field, how its future pillars may look alike, impacted by the uncertainties of the future and the new industrial revolutions – Industry 4.0 and 5.0 as the educators try to incorporate areas like data analytics in manufacturing including machine learning and artificial intelligence (AI), Internet of Things (IoT) and cyber physical systems, digital twins and thread along with other digital manufacturing subjects such as virtual prototyping, 3D scanning, 3D printing and additive manufacturing.

Introduction

History of modern manufacturing has its roots in ancient cultures long before the first Industrial Revolution (Industry 1.0). However, roots of human manufacturing activity are almost associated with the existence of early humans on this planet, as homo habilis produced stone hand axes to satisfy their needs[1]. Manufacturing is a major contributor and wealth generator for any strong economy. According to the statistics published by the National Association of Manufacturers (NAM)[2], U.S. manufacturing companies in 2018 accounted "for 11.39% of the total output in the economy, employing 8.51% of the workforce. Total output from manufacturing was $2,334.60 billion in 2018. In addition, there were an average of 12.8 million manufacturing employees in the United States in 2018, with an average annual compensation of $84,832.13 in 2017".

According to National Institute of Standards and Technology (NIST)'s Manufacturing Innovation Blog[3], "manufacturing engineering is a branch of engineering that focuses on improving the production of an item, whether that's through making product design changes or creating more effective manufacturing processes. Job duties of manufacturing engineers can include developing solutions to production issues, performing cost-benefit analyses, or operating computer-aided design software to design and produce products and systems. Professionals in this field sometimes go by the title plant engineer or process engineer". The definition given by the blog is very limited and covers only a fraction what manufacturing engineers do in practice. A full account of what manufacturing engineering field is explained in the next section.

High percentage of mechanical engineers have been employed in the manufacturing sector along with electrical engineers, material scientists and engineers, and industrial engineers since manufacturing programs produce only a fraction of engineers needed in manufacturing. Manufacturing Innovation Blog[3] lists mechanical engineering as the most popular degree when considering the bachelor's degrees awarded in the U.S., however it claims that "bachelor's degrees awarded in manufacturing engineering and related fields have been steadily growing in the recent past, increasing from 3,503 diplomas in 2007 to 5,649 diplomas in 2016." It also presents a similar trend in graduates of master's degrees in manufacturing engineering and related fields, with an increase from "2,565 diplomas in 2007 to 4,102 diplomas in 2016". These figures include graduates of disciplines commonly employed in manufacturing, referred to as "related fields" by the NIST blog. Actual enrollment of manufacturing engineering and manufacturing engineering technology programs have been much smaller.

The number of manufacturing programs has also been steadily decreasing in the U.S. A recent search of worldwide ABET accredited manufacturing engineering and similarly named programs yielded 26 B.S. degree programs in Manufacturing Engineering as well as 25 B.S./A.S./Diploma programs in Engineering Technology or Manufacturing Engineering Technology[4]. 3 of those 26 engineering programs are found in overseas, 1 in Turkey and 2 in Philippines. 3 of those engineering technology programs are also in overseas, 1 in Kuwait and 2 in Saudi Arabia. Thus, the total number of ABET accredited B.S/A.S. programs focusing on manufacturing in the U.S. is only 45. Without addition of new programs, this count could be even smaller. The author is aware of recent program closures in his vicinity including Community College of the Allegheny County (CCAC)'s Manufacturing Engineering Technology A.S. program as well as Youngstown State University (YSU)'s newly opened B.S. Manufacturing Engineering program. While the author's program in B.S. Manufacturing Engineering had 139 students a few years ago, that number now stands around 20. On the contrary, schools like Brigham Young University (BYU) has seen enrollment figures approaching 200 students.

Most of the major U.S. institutions with ranked Industrial or Industrial and Manufacturing Engineering programs are choosing not to offer standalone manufacturing degrees other than a few exceptions seen in the Tables 1 and 2 (below) including Arizona State University, Purdue University, Oregon State University, and Texas A & M University. Most of manufacturing engineering and engineering technology programs are associated with satellite campuses of those large ranked universities – University of Michigan Dearborn, The University of Texas – Rio Grande Valley, University of Wisconsin Stout or exist at smaller institutions. Often these manufacturing programs are founded with support and encouragement from local industries and in the past by the Society of Manufacturing Engineers (SME) Education Foundation. Many universities are worried about investing in large manufacturing equipment of industrial caliber, and when they invest in those, it is for major research projects, not for teaching manufacturing. Spatial and maintenance requirements are also deterring factors for not starting a manufacturing program, adding to the cost worries. Another drawback of manufacturing education is the name recognition. Students entering engineering education and their families often choose traditional engineering disciplines over manufacturing, and the field is associated with the dirty and grimy days of the past. Prospective students tour manufacturing programs and their laboratories, and mention what they want to do after graduation – basically defining manufacturing engineering. But, when they are asked to choose a program, they prefer mechanical engineering or other fields over manufacturing.

Table 1. ABET Accredited Programs in Manufacturing Engineering[4] as of 02/09/2022

Manufacturing Engineering (21)	Arizona State University, Bradley University (IL), Brigham Young University (UT), California Polytechnic State University - San Luis Obispo, California Polytechnic State University – Pomona, Central State University (OH), Georgia Southern University, **Istanbul Technical University (Turkey), Mapua University (Philippines)**, Miami University (OH), North Dakota State University, Oregon State University, Robert Morris University (PA), Texas State University, St. Cloud State University (MN), The University of Texas - Rio Grande Valley, University of Michigan – Dearborn, University of Southern Indiana, University of Wisconsin – Stout, Virginia State University, Western Washington University	Bachelor's of Science
Product Design and Manufacturing (2)	Grande Valley State University (MI), Wichita State University (KS)	Bachelor's of Science
Management and Engineering for Manufacturing (1)	University of Connecticut	Bachelor's of Science
Manufacturing Engineering and Management (1)	**De LaSalle University (Philippines)**	Bachelor's of Science
Manufacturing Systems Engineering (1)	California State University – Northridge	Bachelor's of Science

Table 2. ABET Accredited Programs in Manufacturing Engineering Technology[4] as of 02/09/2022

Manufacturing Engineering Technology (18)	Bradley University (IL), Brigham Young University (ID), Central Connecticut State University, **College of Technological Studies (Kuwait)*******, East Tennessee State University, Farmingdale State College (NY), Indiana State University, **Jubail Industrial College (Saudi Arabia)****, Lake Superior State University (MI), Minnesota State University, Northern Illinois University, Oregon Institute of Technology, Pittsburg State University (KS)***, Purdue University at West Lafayette, Rochester Institute of Technology (NY), Vermont Technical College, Weber State University (UT), Western Michigan University.	Bachelor's of Science * BS in Manufacturing Engineering Technology **BS in Engineering Technology ***Associate's Degree **** Diploma in Applied Technological Science
Mechanical and Manufacturing Engineering Technology (2)	Lawrence Technological University (MI), Northern Kentucky University	Bachelor's of Science
Engineering Technology in Manufacturing Engineering Technology (1)	Austin Peay State University (TN)	Bachelor's of Science
Engineering Technology: (Option) Manufacturing Engineering Technology (1)	Southwestern Oklahoma State University	Bachelor's of Science

Global Manufacturing Systems Engineering Technology (1)	University of Dayton (OH)	Bachelor's of Science in Engineering Technology
Manufacturing and Mechanical Engineering Technology (1)	Texas A & M University	Bachelor's of Science
Manufacturing Industrial Engineering Technology (1)	Cuyahoga Community College (OH)	Associate's Degree
Manufacturing Technology (1)	**Yanbu industrial College (Saudi Arabia)**	Associate's Degree
Robotics and Manufacturing Engineering Technology (1)	Rochester Institute of Technology (NY)	Bachelor's of Science

What are manufacturing engineering and its curriculum?

Manufacturing engineering is an extremely hands-on and cross-disciplinary field that is almost unlimited in its applications, varying from heavy manufacturing to food processing or electronics, from medical devices to toys or textiles. According to the fairly recent wisdom of

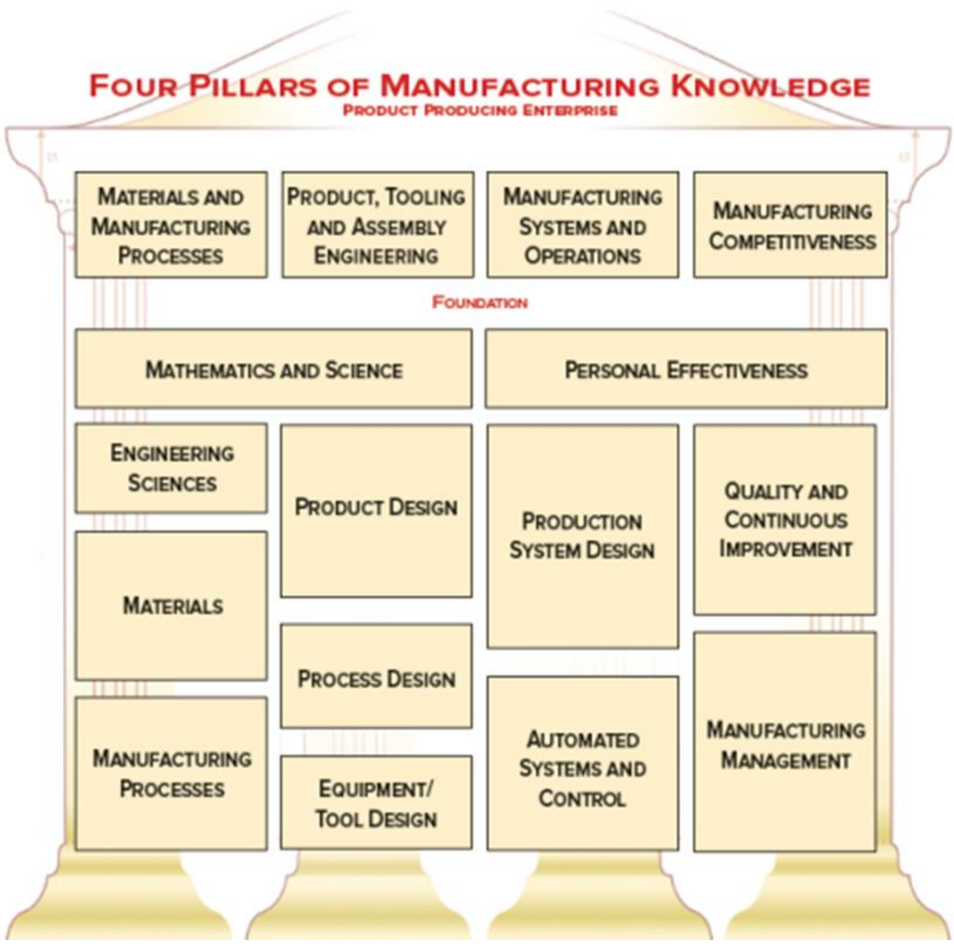

Figure 1. Four Pillars of Manufacturing Engineering of a Product Producing Enterprise[5]

"Four Pillars of Manufacturing Engineering of a Product Producing Enterprise" body of knowledge (BOK) developed by SME, manufacturing engineers need to be prepared and competent in four thrust areas: (i) materials and manufacturing processes, (ii) product, tooling, and assembly engineering, (iii) manufacturing systems and operations, and (iv) manufacturing competitiveness[5]. In addition, a good manufacturing engineering curriculum has to have to a strong foundation in mathematical and science preparation, and personal effectiveness and development content towards valuable soft skills[5]. In detail, the Four Pillars are supported by the following foundation areas as illustrated in Figure 1[5]:

i. Materials and manufacturing processes: (Basic) engineering sciences, materials, and manufacturing processes
ii. Product, tooling, and assembly engineering: Product design, process design, equipment/tool design
iii. Manufacturing systems and operations: Production systems design, automated systems and control
iv. Manufacturing competitiveness: Quality and continuous improvement, manufacturing management

Personal effectiveness defined by the Four Pillars BOK encompass knowledge, innovation ability, creativity, interpersonal skills like negotiating, conflict management, written and oral communication including presentation skills. Life-long learning is another facet that any engineer of the future needs be familiar including manufacturing engineers, to constantly renew their knowledge or re-tool their skills. Emergence of smart devices, abundance of online resources and courses including certificates have made access to information and life-long learning easy.

Appendix A of this paper presents a recently designed B.S. in Manufacturing Engineering program in its entirety including non-engineering, and engineering courses – mandatory and elective. This curriculum was designed to address the technical competencies defined by the Four Pillars BOK and is typical for a manufacturing engineering program. However, its design includes some flexibility with 3 three technical electives to incorporate the changes in the field, such as growth in digital manufacturing and contemporary subjects like Industry 4.0 or 5.0. Often the personal effectiveness preparation of the engineering students including manufacturing ones come from general education requirements or liberal arts components like CMP 120 Expository Writing or CMP 125 Research Writing as illustrated in Appendix A. In a similar way, author's own program requires manufacturing students to take 4 communications skills courses out of the 5 available for non-communications majors:

i. One from: CSEN 1010 Reading & Writing Strategies or CSCM 2050 Intercultural Communications,
ii. CSEN 1020 Argument & Research,
iii. CSCM 1030 Public Speaking & Persuasion,
iv. CSCM 2040 Professional Communications in Workplace.

These 4 communication skills courses lay the foundation for a segment of student personal effectiveness, also allowing students to apply what they learned in those 4 courses in engineering coursework where communication skills are needed, i.e. for researching and developing a research agenda, writing a technical paper or a capstone project report, or prepare a provisional patent application. These engineering courses are deemed to be communication intensive beside serving their own purposes for technical development of prospective engineers. Table 3 also summarizes soft skill requirements developed by engineering and non-engineering professors to be integrated into such engineering content[6]. Soft skill sets given in the table was broken into three categories: defining yourself, being a professional, and practicing ethics. Table 3 not only include the items sketched out in the Four Pillars BOK but also helps students to understand their own identity including self-motivation and -reflection as well as work ethics that is applicable to problem solving and critical thinking of different sorts.

BOX 1 Defining yourself	BOX 2 Being a professional	BOX 3 Practicing Ethics
Individual Values	Team work (establishing team goals, building trust, managing team toxicity, achieving consensus)	Problem Solving (computational thinking, problem-based approaches, modeling)
Dependability	Communication (Written and Oral, but also including Listening)	Responsibility/ Accountability
Self-Motivation	Research	Analysis
Self-Reflection/ Life Management	Leadership (motivation, emotional intelligence, conflict management)	Honest Evaluation of self and Others

Table 3. Soft skills integrated into engineering content[6]

Conclusions and Future of Manufacturing Education

As the disadvantages of offering manufacturing programs outweigh its advantages, the future of manufacturing engineering programs looks not very promising unless larger institutions or major industries get involved. On the contrary, any institution with a good plan and location near a variety of industries or major industry can sustain its manufacturing programs since millions of manufacturing jobs are still available (even though a fraction of these will be engineering jobs) and retiring manufacturing personnel need to be replaced. Bureau of Labor Statistics (BLS) presents that there were 292,000 industrial/manufacturing engineering jobs available in 2020 and it expects a 14% increase (faster than average) in that figure between the years of 2020-2030, adding another 40,000 new positions[7]. In addition, some of the future manufacturing technician and engineering jobs will involve knowledge and skills sets which can be applicable to other fields. In the case of manufacturing engineers who are competent in the area of smart manufacturing, namely Industry 4.0, especially in Industrial Internet of Things (IIoT) can find themselves be working in the area of Internet of People (IoP) due to their sensor, software, networking, and security background.

The validity of advanced or high-tech manufacturing fields such as industrial robotics (including collaborative robots) and automation, programmable logic and automation controllers (PLCs and PACs), computer-aided manufacturing (CAM) and computer-numerically controlled (CNC) machines, 3D scanning, 3D printing and additive manufacturing will continue. And with the spread of new technologies, we will also see an expansion from digital manufacturing to smart manufacturing[8]. Industry 4.0 or 5.0 will drive the future of manufacturing, manufacturing engineering, and its study with machine learning and artificial intelligence (AI), digital twins along with computer-aided engineering (CAE), digital threads, IIoT and cyber-physical systems, and extended reality (augmented reality AR, augmented virtuality or virtual reality (VR), and hybrid reality (HR) areas. All of these fields will greatly impact the design of three pillars of the Four Pillars BOK – including product, tooling, and assembly engineering with help from digital twins, manufacturing systems and operations utilizing manufacturing analytics and AI, and manufacturing competitiveness benefitting from predictive maintenance and machine learning. As a final word, the manufacturing engineers of the future need to be versatile to be quickly adapting to the changes in their environment and strong in digital and smart manufacturing, and be as a resilient as a hands-on consultant in case they have to be one.

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Appendix A – A sample BS Manufacturing Engineering program

BS Manufacturing Engineering

v. 11-19-'18

Freshman Year

Fall

First Semester		Total 17
MTH 210	Calculus I	4
*MTH 105 or Math SAT 650 or higher or Math ACT 28 or higher		
CHE 120	Principles of Chemistry	3
CHE 121	Principles of Chemistry Lab	1
**CHE 120		
ENR 101	Introduction to Engineering	3
CIS 300	Object Oriented Programming	3
	ONE FROM:	
CMP 120	Expository Writing	3
BHP 100	Honors Seminar: Great Ideas I	3

Spring

Second Semester		Total 17
ENR 120	Engineering Graphics* ENR101	3
MTH 211	Calculus II	4
*MTH 210		
PHY 200	Gen. Physics I* MTH 210 or concurrent	3
PHY 200L	General Physics I Lab** PHY 200	1
ENGR210	Engineering Materials	3
*CHE 120 and CHE 121		
	ONE FROM:	
CMP 125	Research Writing	3
BHP 150	Honors Seminar: Great Ideas II	3
CMP 203	Literature and Composition	3

Sophomore Year

Fall

Third Semester		Total 17
ENR 160	Statics & Strength of Materials	3
*MTH 210, PHY 200 AND PHY 200L, or concurrent		
MTH 212	Calculus III	4
*MTH 211		
PHY 201	General Physics II* PHY 200 and MTH 211 or concurrent	3
PHY 201L	General Physics II Lab** PHY 201	1
COM 104	Speech Communication	3
ENR 250	Engineering Econ and Entrepreneurship	3
*Sophomore standing		

Spring

Fourth Semester		Total 15
ENR 220	Circuits and Electromagnetics	3
*PHY 201 and PHY 201L		
MFE 340	Manufacturing Processes	3
*ENR 160 and ENGR210, or concurrent		
MTH 340	Probabibility and Statistics I	3
*MTH 212 or MSD 111		
MTH 240	Linear Algebra	3
*MTH 210 or as concurrently; sophomore standing or permission of instructor.		
	ONE FROM:	
CHI 10X, 20X	Chinese I.. IV	3
FRE 10X, 20X	French I..IV	3
SPA 10X, 20X	Spanish I..IV	3

* Pre-requisite
**Co-requisite

B.S. Manufacturing Engineering

Junior Year

Fall

Fifth Semester		Total 15
MFE 360 *MTH 340	Intro. To Quality Engineering & Lean Princip	3
MFE 370 *MTH 340	Mfg. Planning & Control	3
MTH 250 *MTH 240, MTH 211, and MTH 212 or concurrently	Differential Equations	3
HIST 150	World History to 1500	3
	ONE FROM:	
CHI 10, 20X	Chinese I.. IV	3
FRE 10X, 20X	French I..IV	3
SPA 10X, 20X	Spanish I..IV	3

Spring

Sixth Semester		Total 15
MFE 410 *Junior standing	Industrial Electronics and Device Co	3
MFE 350 *ENR 120 and MFE 340	Product, Process, and Tool Engine	3
THE 106	Theather History Since 1700	3
MGT 201	Fund. Of Management & Org. Lead	3
	ONE FROM:	
SOC 101	Sociological Imagination	3
POL 100	Introduction to American Politics	3

Senior Year

Fall

Seventh Semester		Total 15
MFE/ENR xxx	Manufacturing Eng. Elective	3
MFE/ENR xxx	Manufacturing Eng. Elective	3
MKT 200	Marketing Principles	3
	ONE FROM:	3
SUS 100	Introduction to Sustainability Studies	3
GEO 113	Environmental Geology	
	ONE FROM:	3
ENG 218	Literature and the Environment	3
ENG 224	Science Fiction	

Spring

Eighth Semester		Total 15
ENR 490 *Senior standing	Engineering Design Capstone	3
MFE/ENR xxx	Manufacturing Eng. Elective	3
COM 105	Communication, Culture, and Medi	3
HIST 151	World History since 1500	3
	ONE FROM:	
PHIL 110	Logic and Language	3
PHL 115	Ethics	3

Total Credits 126

B.S. Manufacturing Engineering Electives 300 - 400 Level Only

MFE/ISE 420 *MTH 340	Discrete Event Simulation	3
MFE/ISE 430 *MTH 340	Safety and Methods Engineering	3
MFE/ISE 440 *MFE 370	Material Handling & Plant Layout	3
MFE 450 *ENR 120 and MFE 350	Digital Manufacturing	3
MFE 460 *Senior standing	Engineering Practice	3
MFE/ISE 470 *MFE 410	Automation and Robotics	3
ENGR 480 *Senior standing	Project Engineering	3
MFE 490 *Senior standing	Contemporary Subjects in Mfg. Eng	3

*Pre-requisite
**Co-requisite