

AC 2009-1055: ROLE OF MANUFACTURING PROGRAMS IN ENGINEERING WORKFORCE DEVELOPMENT

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Role of Manufacturing Programs in Engineering Workforce Development

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Abstract:

The project leading to this paper was carried out as part of SME's efforts to prepare the manufacturing curricula for the year 2015 and beyond. In doing so, it considered the role of manufacturing in the global economy, the factors affecting the scope of manufacturing, and the current efforts to revitalize manufacturing in the various parts of the world. It then reviewed the curricular models proposed to address the needs of the manufacturing industry. As an extension of the analysis, recommendations were made on the key aspects of a manufacturing curriculum with an emphasis on innovation and entrepreneurship. Further, the recommendations included the creation of a flexible degree program that emphasized learning over teaching, development of a network of academic institutions around the globe to deliver the program, use of communication technologies to provide access to the program to anyone at anytime and anywhere in the world, and an outreach to future manufacturing professionals. The paper presents the results of the study.

Contents:

1. Introduction
2. Current Context of Manufacturing
3. Transformation in Manufacturing
4. Global Strategies for the Growth of Manufacturing
5. Worldwide Educational Programs to Promote Manufacturing
6. Manufacturing Competencies – A Recommendation
7. Strategies for Enhancing the Role of Manufacturing Education
8. 8. Summary
9. References

1. Introduction

For over 100 years, manufacturing has been a major contributing element of the economy in many of the developed countries. In recent times, the changes in manufacturing in the USA, the countries of Europe and elsewhere have raised questions and concerns about the extent to which manufacturing will continue to influence the future of the economy in those countries. Consequently, there have been efforts in the public and private sectors to develop and implement strategies and ensure that manufacturing continues to play a vital role in the economy. In many cases, these efforts have been either regional in nature or country specific. However, the results of these ongoing efforts may determine the scope of public and private investment in new technologies and the extent to which the growth of manufacturing is influenced in the coming years. They may also determine the approaches taken to develop the engineering and technological workforce needed to meet the needs of the manufacturing industry.

This paper reviews some of the factors affecting manufacturing in the USA and elsewhere, the strategies that are being considered to enhance manufacturing, and the role of education as a strategic element in enhancing the manufacturing activity. It proposes the aspects of a curriculum that should be considered to develop a strong manufacturing workforce. It also presents a set of strategies to enhance manufacturing education.

2. Current Context of Manufacturing

In order to review the factors affecting manufacturing and the strategies that are being employed to revitalize the industry, this section presents a brief overview of the current economic status, the scope of manufacturing, the level of employment in manufacturing, and the investment in research and development in countries around the world. Although there are a number of other factors that may offer further insight into the relative strength of global manufacturing, for the purposes of this paper, the discussions are limited to the items identified.

Table -1 summarizes the current gross domestic product (GDP) for 15 countries of the world. Since the GDP is a measure of all final goods and services produced within a country in a given year, the table indicates that the top five countries of the world account for the bulk of the world's goods and services produced. The USA accounts for more than 30% of the world's economic activity.

Figure – 1 presents the share of manufacturing activity in different parts of the world as of 2005. While the USA by itself accounts for about a fourth of the world's manufacturing, USA along with Japan and the countries of European Union carry out more than 60% of world's manufacturing activities.

Table - 1. Relative size of the US Economy in the World
(Source: J.P. Morgan – 2008)

	Percent share of GDP
USA	30.5
Japan	13.9
Germany	5.6
China	4.9
United Kingdom	4.5
France	4.0
Italy	3.2
Spain	1.9
Brazil	1.9
India	1.7
Australia	1.3
Netherlands	1.1
Russia	0.9
Switzerland	0.7
Turkey	0.7

Figure-1 Manufacturing in the World
(Source: OECD STAN Indicator Database – 2005)

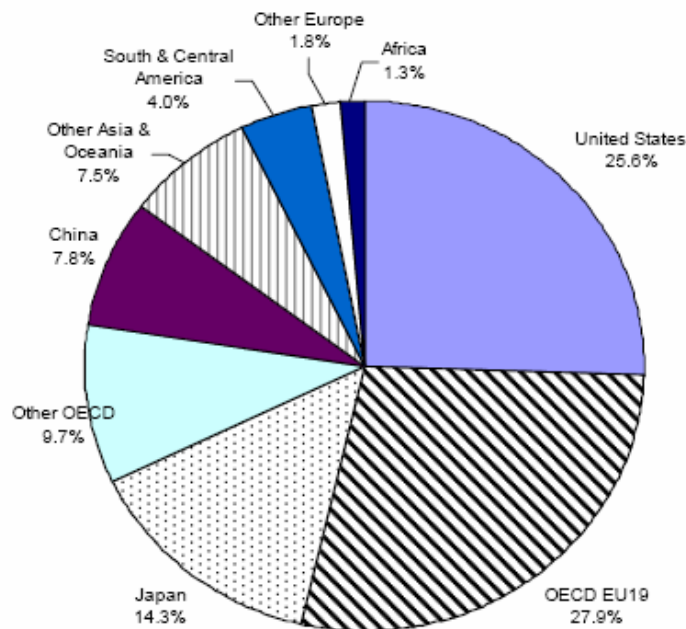


Figure -2 presents another view of the worldwide manufacturing activity. In this case, the manufacturing activity in value added terms for the group of seven leading industrialized (G-7) countries is presented for the period from 1970 to 2002. Presented in terms of 1980 prices, the figure indicates that in most recent times, the USA and Canada have led the G-7 countries in manufacturing productivity. There has been a continuous productivity increase for more than ten years.

Figure – 3 presents another perspective on the manufacturing productivity in the USA. For the period from 1977 to 2003, USA’s manufacturing productivity has outpaced the overall growth of the country’s economy. More importantly, the manufacturing productivity has increased at an accelerated pace in recent times.

Figure – 4 presents the data relating to manufacturing employment in the G-7 nations. There has been a continuous decline in the absolute number of people employed in manufacturing in all of the G-7 countries. However, the rate of decline is relatively less in the case of Canada and Italy in comparison with the decline in the USA, UK and Japan.

Figure – 5 presents a closer view of the manufacturing employment in the USA for the period from 1977 to 2003. While the overall economy maintained a steady growth in the employment during this period, employment in the manufacturing sector saw a continuous negative growth. It should be noted that during the same period, the rate of manufacturing productivity far outpaced the over all growth of the economy.

Fig.2. Worldwide Value addition to Manufacturing: 1970 – 2002
 (Based on Constant Prices with 1980 =100)
 (Source: OECD STAN Indicator Database – 2005)

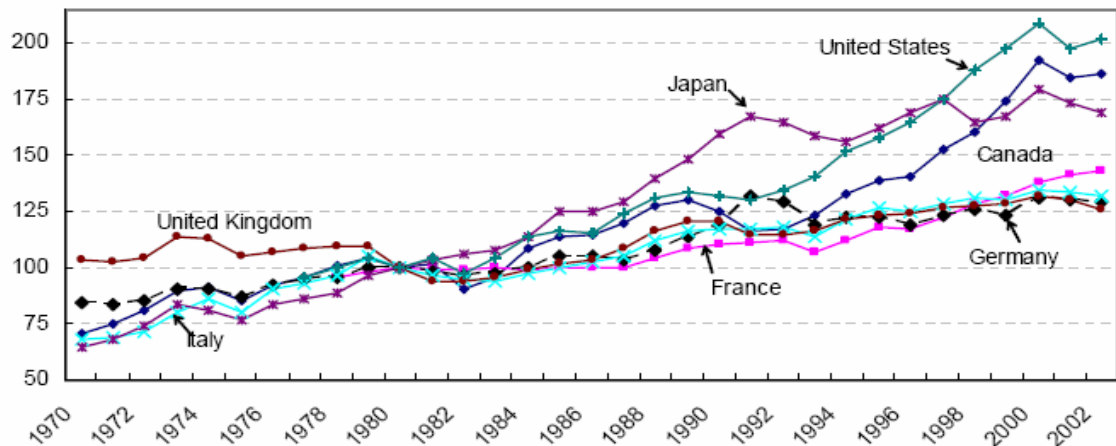


Fig. 3. Productivity in Manufacturing and the Total US Economy (1977 – 2002)
(Source: US Commerce Department)

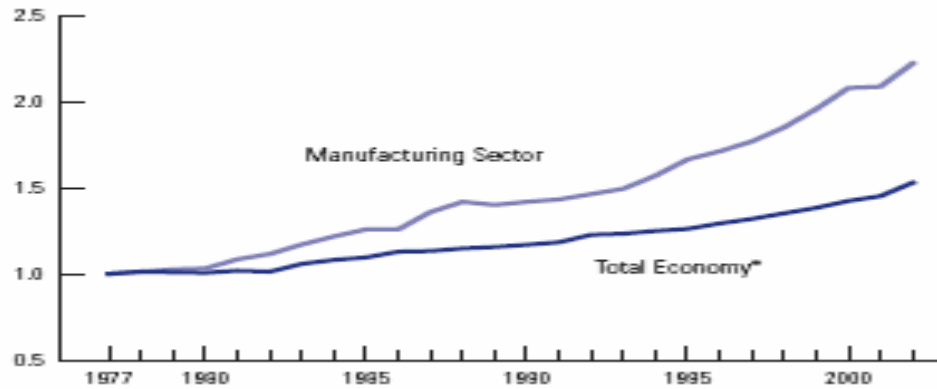


Fig. 4. Share of Manufacturing in Total Employment in the World (1977 – 2003)
(Source: OECD Labor Statistics 2005)

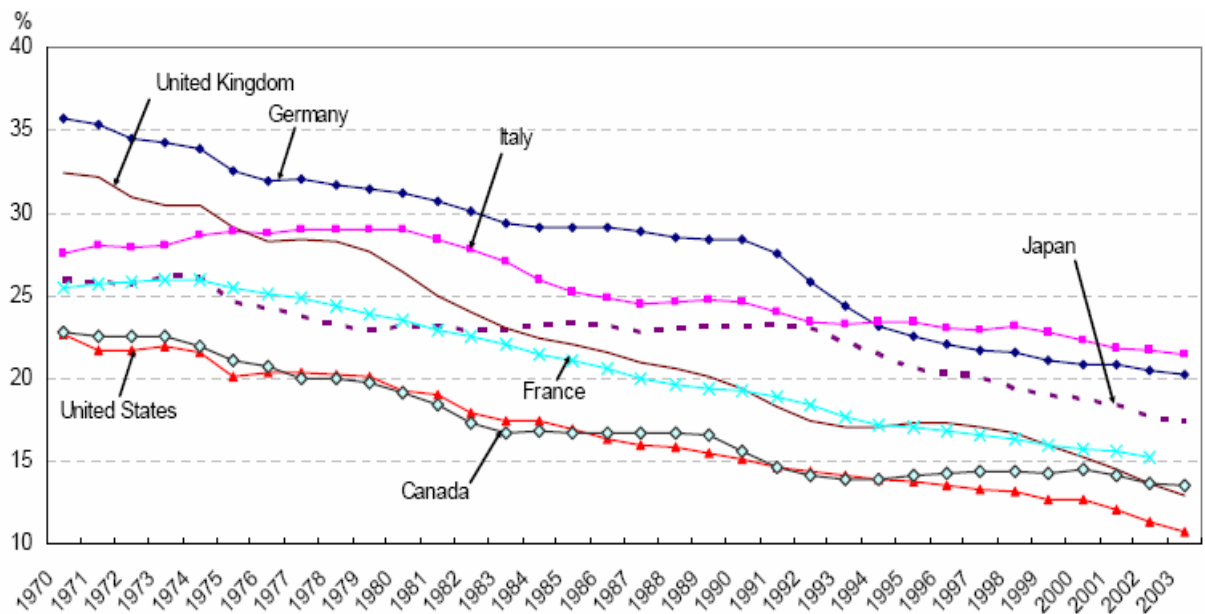


Fig. 5. US Manufacturing Employment vs Total Employment (1977-2002)



In considering the comparative status of manufacturing in various parts of the world, it is the norm to look at the cost of labor as a factor. Table – 2 presents the cost of labor in seven global markets. While much has been written about this, more recently factors such as the cost of energy, and the cost of transportation are also considered to be very important in determining the cost of production.

Table -2. Relative Cost of Manufacturing Labor in the USA (2005)

	Cost Per hour in US \$
USA	30
Japan	24
W. Europe	24
Mexico	4
E. Europe	3
China	2
India	1

Table -3 presents the data on the public investments in research and development (R&D) around the world. USA maintains the lead role in investing in R&D. However, the data shows that China has started making investment in public R&D at a rate that is much faster than any other country in the world. It should also be noted that the rate of growth R&D investments in Europe is stagnant.

Table -3 . Global Investment in R&D
(Source: Science and Technology Indicators, NSF, Aug 2008)

	R&D Investment (in Billions of \$)	
	2002	2005
North America	300	325
Europe	234	240
Japan	98	130
China	40	105
All of Asia	146	270
South America	18	24
Africa	5	8

3. Transformation in Manufacturing

The manufacturing industry today is undergoing a major transformation. This can be compared to some of the transformations of the past. From a historical perspective, today's transformations is no less significant when compared to the industrial revolution of the 18th century, the introduction of mass production techniques in the early part of the 20th century or the introduction of automated manufacturing with the invention of computers, numerical control systems and robots in the later half of the 20th century. The current transformation will have no less impact on the future of manufacturing than the past transformations.

From a broader perspective, the factors driving the current transformation in manufacturing are: 1) globalization of manufacturing, 2) growth in the global manufacturing workforce 3) advances in manufacturing technologies. Figure – 7 illustrates the scope of these factors in the transformation of manufacturing. In the figure, the origin presents the localized manufacturing scenario while the X- axis presents the case of moving towards global operations, the Y-axis presents some of the advances in global workforce competencies and the Z axis outlines the advances in manufacturing technologies. An account of these factors and their role in manufacturing transformation is presented in the following paragraphs.

Z . Advances in Technology

- Digital and communication technologies
- Fabrication and assembly technologies at the macro level
- Micro and nano scale processes
- Virtual manufacturing
- Transportation and logistics technologies
- Business and management practices

Y . Advances in Workforce Competencies (Globally)

New workforce with :

- Engineering and technological competencies
- Research and product development capabilities
- Capabilities to innovate
- Management and business competencies

X . Globalization of Manufacturing

- Distributed design, fabrication and assembly
- Emergence of new markets / competitors
- Emergence of new entrepreneurs
- Challenges in logistics (information /material)
- Emergence “ manufacturing service” providers
- Multi-cultural environment
- Political / social / human / ecological factors

0. Localized Manufacturing

- Localized design/ fabrication / assembly
- Limited competition
- Adequate workforce competencies
- Research and product innovation limited to parts of the world
- Access to the resources needed

Figure -7: The factors affecting the scope of manufacturing

First, manufacturing has moved from being localized operations to global manufacturing primarily due to the advances in digital, communication, transportation and other technologies. It has also occurred due to the unprecedented developments and growth in educating the manufacturing workforce in places where manufacturing was insignificant only 20 years back. Global manufacturing is also driven by the arrival new entrepreneurs in many parts of the word. Equipped with world-class infrastructure for finance, marketing and other areas, a capable workforce, and forward looking governmental organizations, the new entrepreneurs have come up to take control of global manufacturing and exploit new markets. The growth in global manufacturing is also the result of the “never-ending search” to pay the least for the manufacturing workers. Over

the last two decades, the manufacturing organizations in the developed countries have used low cost labor as a means to justify moving manufacturing operations to global destinations.

The growth in the global manufacturing workforce is yet another cause for the current transformation. With the emergence of a new political order in many parts of the world since the 1950s, countries that are large and small have invested a sizable share of their national resources to educating an engineering workforce. Started with Taiwan and Korea in the 1950s, and China, India and the others most recently have built up their educational infrastructure to produce large number of engineering graduates capable of supporting the competency requirements of global manufacturing operations. The educational systems in those countries do not limit themselves to developing a technological workforce, instead they are preparing world-class entrepreneurs, capable of managing and challenging the established global order in business, finance and other sectors of the economy. There have been an unprecedented commitment to education that is at the individual and at the collective level. Those commitments have helped develop and promote education from the primary to the tertiary level. Although initiated in the beginning as a means to attain higher standards of living, today the drive is to attain excellence in industrial and economic development. One can not, and should not ignore the fact that the drive in many countries is not limited to developing a workforce to meet the current skills requirements of the industry, but to develop their tertiary education and become a strong force in research and innovation.

The third most important factor that is driving the transformation in manufacturing today is the growth in technology. There have been unprecedented progress in the technologies used for product design, fabrication, assembly and how the products are marketed and distributed. The technological advances in fabrication and assembly at the macro, micro and nanoscale level are major contributors to the current transformation. In a wide variety of fields ranging from agricultural to biological, metals to plastics, and from medicine to pharmacy, the advances in the associated manufacturing processes have expanded the scope manufacturing industry. The advances in the processes are complemented by the advances in areas such as materials science, electronics and instrumentation. The application of computers and communication technologies have helped “global manufacturing” reach its current status. Product design, fabrication and assembly are no longer constrained to a local operation. They could be at different locations, any where in the world, and integrated at all levels to make the concept of “virtual manufacturing” a reality. The “digital technology” and the “digital business” are technological and management concepts arising from the application of computer and communication technologies along with new business concepts contributing to the development of “global manufacturing outsourcing” operations and the “manufacturing service providers”. The service providers form the key element of the global “supply chain”. In most cases, they manufacture the product components, sub assemblies and even finished products and provide a cost advantage to the “global manufacturing organization”.

The advances in communication technologies have especially made it possible to share product and process information at anytime of the day and anywhere in the world. They

have also enabled the control of processes in real-time. The logistics of material movement, and the management and control of information associated with the material movement have created a global “supplier- customer” operations. The concept of “virtual manufacturing” has come about mainly due to the ability to share and manage information globally, convert a design originating from one place into a finished product elsewhere. This virtual manufacturing concept has made it possible for some of the leading manufacturing organizations in aerospace, defense and other industries to become system integrators. They design systems in one location and manufacture components, and sub assemblies in other locations and transport them for final assembly at yet another locations.

4. Global Strategies for the Growth of Manufacturing

To meet the challenges and the opportunities arising from global manufacturing, efforts are currently under way in industry, government and academia in many parts of the world. Noteworthy among them are the efforts in the USA to provide public sector support to research and development; the European Union’s efforts to establish a collective reform for the expansion of manufacturing; the UK’s strategic directions for the future of manufacturing; the programs of the Ministry of International Trade and Industry (MITI) in Japan to maintain the country’s global position in manufacturing and China’s central plans for industrial growth. The following presents the key aspects of the manufacturing strategies in various regions.

i) European Union’s Strategy for the Future of Manufacturing

In recognition of the importance of manufacturing to the future of the European Union (EU), a number working groups of EU undertook a study during 2003 and considered the role of industrial research in the growth of manufacturing, and a vision for European Manufacturing. The group considered EU’s technological competitiveness, the strengths, weaknesses, opportunities and threats of EU manufacturing, the investment needed for manufacturing related research, and the long term goals for the EU manufacturing industry. The study concluded that there was need for change, “primarily to permit an evolution from resource-based to knowledge-based manufacturing”.

A working document that resulted from the study recommended the following as strategic actions:

- Increased research and technological development
- International cooperation in manufacturing research
- Emphasizing the key role of education and training
- Creating a stimulating operating environment for industrial innovation
- An increased emphasis on the competitiveness of European research

ii) UK's Strategy for the Future of Manufacturing

In the Fall 2008, the UK Department for Business Enterprise and Regulatory Reform (BERR) reaffirmed the UK government's continued commitment to the growth of the manufacturing industry by announcing its strategy for the long term success of manufacturing. It included the following elements:

- ***Sustaining Macroeconomic Stability*** – allowing businesses to plan for the long-term
- ***Encouraging Investment*** – supporting investment in capital equipment and processes, leading edge technology, skills development, and Research and Development
- ***Promoting Science and Innovation*** – helping manufacturers exploit the UK's strong science base to create innovative, high value products
- ***Spreading Best Practices*** – helping companies to raise productivity through continuous improvement and lean manufacturing techniques
- ***Raising Skills and Education*** – supporting the development of a skilled and flexible manufacturing workforce
- ***Providing a Modern Infrastructure*** – providing effective transport and communications networks
- ***Providing the Right Market Framework*** – providing the supportive business environment that manufacturing needs to compete globally

iii) USA's Approach to Strengthen Manufacturing

In 2003, the US Department of Commerce launched an initiative to develop a strategy designed to ensure “that the government is doing all it can to create conditions” necessary to foster US competitiveness in manufacturing and stronger economic growth. It resulted in the following recommendations and action plans:

Enhancing Government's Focus on Manufacturing Competitiveness

- Creating a sub-cabinet level position to promote manufacturing
- Creating an Advisory Council to implement Presidential Initiatives on manufacturing
- Fostering coordination and cooperation among federal, state and local agencies
- Creating an interagency working team to implement manufacturing initiatives

Creating the Conditions for Economic Growth and Manufacturing Investment

- Tax benefits to attract capital and investment in manufacturing
- Reducing costs of tax complexity and compliance
- Offering research and experimentation tax credit
- Strengthening the pool of investment capital available

Lowering the Cost of Manufacturing in the United States

- Reduce the cost and improve the availability of health care
- Modernize legal system to eliminate disincentives to invest in manufacturing
- Reduce the cost of regulation and legislation
- Enact comprehensive energy plan
- Promote pension reform

Investing in Innovation

- Review federal R&D funding for generic technologies, engineering and physical sciences to encourage better coordination and focus on innovation and productivity enhancing technologies
- Identify priorities for future federal support for advanced manufacturing technology
- Create an interagency working group on manufacturing research and development
- Strengthen US Patent and Trademark processing mechanisms
- Strengthen partnerships to promote manufacturing technology transfer
- Expand cooperative technical assistance programs on standards
- Ensure reliability of the critical infrastructure that is vital to manufacturing
- Support a manufacturing extension partnership and create a National Virtual Network Centers of Manufacturing Excellence
- Encourage Small Business Research and Small Business Technology Transfer to focus on manufacturing
- Explore new avenues for leveraging unique capabilities of the national laboratories and universities for the benefit of small and medium sized manufacturers

Strengthening Education, Retraining, and Economic Diversification

- Enhance workforce skills essential for employment in the manufacturing enterprise of the future
- Establish high school and technical education partnership initiative
- Establish personal reemployment accounts
- Coordinate economic programs for manufacturing communities
- Improve delivery of assistance for retraining of displaced workers

Promoting Open Markets and creating a Level Playing Field

- Encourage economic growth and open trade and capital markets abroad
- Negotiate trade agreements that benefit US manufacturers

- Enforce US trade agreements and combat unfair practices affecting US manufacturers
- Reinforce the efforts to promote the sale of American Manufactured Products in Global Markets

In addition to the approaches outlined, the US Interagency Working Group on Manufacturing, established by the National Science and Technology Council has identified hydrogen technologies, nanotechnologies and intelligent and integrated manufacturing as the most prominent technological areas for federal research and development funding. The following outlines the priorities for research in each of these areas:

Manufacturing R&D for Hydrogen Technologies

- Reliable manufacture of hydrogen production, fuel cell components and systems to ensure replacement of petroleum with hydrogen
- Domestic infrastructure for low cost, high volume manufacture and supply of hydrogen power
- Infrastructure for the manufacture of affordable fuel cell vehicles

Nanomanufacturing

- Enabling the mass production of affordable nanoscale materials, structures, devices and systems

Intelligent and Integrated Manufacturing

- Application of advanced software, sensors, controls, networks and other information technologies to achieve rapid, cost-predictive development of innovative products and processes and highly efficient production machines and systems that can be easily adapted and reconfigured in response to changing requirements and new opportunities.

Irrespective of the origin of the global efforts to promote manufacturing, there are many common elements in the plans and their undertakings. They include investing in research and development, promoting innovation, leveraging technological advantages, and developing and maintaining a highly competent engineering and technological workforce. Although the extent of implementation of these strategies and their impact on manufacturing in various parts of the world are yet to be determined, it is certain that the development of engineering and technological workforce for manufacturing has been at the center of the efforts in every region of the world.

5. Worldwide Educational Programs to Promote Manufacturing

As one of the means to enhance manufacturing activity in various parts of the world, country specific, regional, and international efforts have been under way to strengthen the manufacturing education. While new educational and training programs in manufacturing are developed, existing programs are revised and updated. Special programs are being created to address the needs of advances in technologies, and unique arrangements are being made for on-the job education in areas where such arrangements are appropriate. While these efforts are helping address some of the demands of manufacturing, there are continuing challenges in meeting the needs of the changing manufacturing world.

This segment of the paper reports the efforts of two major international entities, namely the Society of Manufacturing Engineers (SME) in the USA and the Intelligent Manufacturing Systems (IMS) in Europe in preparing the manufacturing engineering workforce. For more than half a million manufacturing engineers, executives and professional members in about 70 countries around the globe, SME serves as the source for knowledge, networking and skills development and help them advance in their chosen fields of manufacturing. SME has also been the agency responsible for developing and helping implement the criteria for accreditation of the collegiate level manufacturing engineering and technology programs.

The Role of SME

The Society of Manufacturing Engineers (SME) initiated a process in 1985 to study the skills and competencies needed in the manufacturing industry and develop curricular models for implementation by the academic institutions. The process expanded in scope and operation over a ten year period to the point that in 1994, a series of workshops organized by the Education Committee of SME produced a formal document entitled “Curricula 2002” that included recommendations for curricular contents for the manufacturing engineering and manufacturing engineering technology degree programs at the baccalaureate and masters level. The recommendations of Curricula 2002 have not only been the basis for many of the manufacturing programs established since 1995, they have also served as the foundation to establish the criteria for accreditation of manufacturing engineering and technology programs.

In 2008, SME initiated a review of the recommendations of Curricula 2002 and a study of the skills and competencies needed for the long term growth of the manufacturing industry. The process started with the First Manufacturing Education Leadership Forum in Pittsburgh, PA in June 2008. A diverse, group of invited guests representing academia, industry, and government met to assess the need for continuing development, upgrading, and updating of manufacturing education programs. The workshop recommendations are currently being compiled for publication as “Curricula 2015” document. Since it is the work-in-progress document, it will take its final shape after SME’s Manufacturing Education Conference, scheduled for June 2009 in Austin, Texas. At the time of writing of this paper in September 2008, the recommendations from the SME team include the following as the key components of the manufacturing degree programs:

a. Technological Competencies - Product Realization Process

- Engineering Materials
- Engineering Mechanics and Design
- Manufacturing Processes
- Manufacturing Systems Design, Analysis, and Control
- Control of Machines
- Quality Systems
- Computer Systems
- Electrical Circuits and Electronics

b. Professional Competencies

- Communication
- Global Multiculturalism
- Teamwork
- Ethics
- Creativity and Innovation
- Enterprise Management
- Manufacturing Information Systems
- Product Life Cycle Management
- Enterprise Resource Management
- Financial Management
- Human Resource Management and Supervision
- Entrepreneurship
- Intellectual Property Rights

c. Mathematics and Science Competencies

- Mathematics
- Physics
- Chemistry
- Bioscience

The Role of IMS

Intelligent Manufacturing Systems (IMS) is an industry-led international research and development initiative established to develop the next generation of manufacturing and process technologies. International businesses, educational institutions, private and public research entities and the governmental agencies in Europe, Asia, Australia and the USA are part of IMS. The following governmental agencies serve as the hosting organizations in the respective regions: the European Commission; Ministry of Economy, Trade and Industry, Japan; Ministry of Commerce, Industry and Energy, Korea, Commission for Technology and Innovation, Switzerland, and the Department of Commerce, USA. IMS

as an international entity is managed and supported by the constituent member organizations.

One of the initiatives of IMS is the project on Global Education in Manufacturing (GEM). Started in 2002, the project led to the creation of a masters level program in manufacturing. The initial partners of the project included twenty-seven organizations from Australia, Europe, Japan, Korea, and the United States. The objectives of GEM were: a) to define the needs of the global manufacturing industry for training and education in manufacturing strategy, b) to develop curriculum to comply with the concept of digital business and extended products, and c) to develop detailed specifications for a manufacturing strategy curriculum focusing on manufacturing engineering and business administration topics. In developing such a program, the following were used as guiding principles:

- seek strong involvement of industry
- seek wider coverage in each region
- seek the involvement of leading universities all over the world
- focus on meeting the future needs of industry
- recognize and acknowledge the cultural differences in global operations
- assure that the program addresses issues of technology, business, management and entrepreneurship
- utilize computer and information technologies to deliver the program
- plan for wide dissemination of information

The masters program developed by GEM addresses the following issues faced by the global manufacturing industry:

- How to work in teams that are interdisciplinary in nature?
- How to develop synergy in teams that have diverse skills?
- How to develop effectiveness and efficiency in groups that represent global cultures?
- How to share information pertaining to tasks at any time and anywhere on the globe?
- How to work in virtual manufacturing organizations?
- How to utilize the tools of information technology effectively for communication and information sharing?
- How to deliver manufacturing education and training to workers any where?

GEM's curriculum addresses the following skill areas:

- Development of extended products
- Digital business along supply chain
- End-of life planning and operation
- Business operation and competitive strategy
- Intelligent manufacturing processes
- Intelligent manufacturing systems design
- Enterprise product modeling and simulation

The curriculum related works of SME and IMS are only two of the prominent efforts globally to develop or revitalize the manufacturing workforce. There have been other efforts and programs around the world to address the development of skills and competencies needed in the manufacturing industry.

6. Manufacturing Competencies – A Recommendation

In this paper, we propose a set of manufacturing competencies that are basically in line with SME's revised curricular model, Curricula 2015 (SME: June 2008) as well as IMS's recommendations for global education in manufacturing. The differences between this model and the others are in the added emphasis on the skills relating to innovation and entrepreneurship and the application of such technologies as nanomanufacturing and biomanufacturing. The following lists the proposed competencies / knowledge base for manufacturing:

a. Fundamentals:

- Science and Mathematics
- Language and Communication
- Social Sciences and Humanities
- Computer and Information technology Fundamentals

b. Extended Product Design

- Product design for manufacturing and remanufacturing
- Product Design for operation, maintenance and end-of-life disposal
- Product modeling and simulation
- Manufacturing system design
- Manufacturing system simulation
- Product quality planning and management

c. Manufacturing Technologies:

- Fabrication and assembly processes
- Manufacturing processes (by the nature of material and processes)
- Manufacturing systems
- Material handling processes and systems
- Manufacturing process simulation
- Sustainable manufacturing
- Processes and product quality

d. Manufacturing Resources and Life Cycle Management

- Production logistics and management
- Product quality management
- Supply chain logistics and management

- Extended manufacturing enterprise operations and integration
- Digital business along supplier and customer chain
- Manufacturing personnel resources management
- Product operation, maintenance and customer service
- Life cycle management and remanufacturing
- Extended manufacturing enterprise modeling / simulation / operation

e. Innovation

- Research and development
- Developing breakthrough products and services
- Technology transfer and product realization
- Commercializing manufacturing technologies
- Manufacturing technology management

f. Entrepreneurship

- Business concepts and entrepreneurship for manufacturing
- Establishing and running manufacturing / related technology based business
- Emerging manufacturing markets and setting up a business
- Managing a manufacturing business in the global context
- Virtual manufacturing and remote operations
- Global manufacturing - supplier / customer functions
- Business economics and manufacturing

g. Biomanufacturing

- Principles and application of bio manufacturing operations
- Bio materials and processing of biomaterials
- Fermentation technology
- Genetics engineering
- Pharmaceutical material processing
- Nanoparticles in pharma manufacturing
- Manufacture of medical devices and implants

h. Nano manufacturing

- Nanomaterials / fabrication techniques
- Nano fabrication systems
- Nanoscale measurements / nano product characterizations
- Nanomanufacturing applications
- Nanoelectronics
- Bionano processes

i . Practical Experience

- Experience in the form of internships / co-ops
- Global internship in another country / culture / social environment
- Prolonged industry apprenticeship

7. Strategies for Enhancing the Role of Manufacturing Education

The future of manufacturing will depend upon the bold steps taken to prepare a competent workforce and a new generation of entrepreneurs. In the context of global manufacturing, the manufacturing professionals must be prepared not only to seek jobs in established businesses, but to create jobs by establishing new manufacturing businesses. Entrepreneurship must become part of the educational process for the future manufacturing professionals. Further, the efforts to prepare the workforce should place an increasing emphasis on student learning over teaching. The traditional educational process has emphasized the teaching methods as the primary means to prepare a competent workforce. The future efforts towards the development of manufacturing professionals must break the traditional barriers in creating educational opportunities, utilizing the advances in digital and communication technologies and delivering programs all over the world. Manufacturing education must be made available to anyone interested in it, anywhere in the world and at any time they like to learn. Extensive collaboration among the leading educational institutions and industry in a given country or around the world must become part of the means to prepare the future manufacturing workforce. Organizations such as SME, IMS and others should become change agents and enable extensive global academic and industry collaboration, ongoing changes in curricular content to address the needs of industry, emphasis on learning over teaching, programs to develop a new generation entrepreneurs, and provisions for access to manufacturing education at any time and anywhere. Beyond preparing a competent workforce through the educational process outlined, the change agents must assume the responsibilities in educating the public on the scope and the prospects of manufacturing in the future. They must also become the leading proponents to shape the policies of the governments at all levels.

We propose the following as a feasible approach to implement the recommendations made in this section:

- Create a network of global academic institutions aimed at developing and offering a universal manufacturing degree program
- Develop and make available a spectrum of courses covering the competencies needed in industry
- Develop a universal degree program that is flexible, accessible and would meet individuals needs for manufacturing competencies
- Entrepreneurship must be a strong component of the degree program

- Enable the member institutions in the network to select areas of interest and build the degree program around those areas and yet meet the expectation of the universal degree. The program should be structured so as to allow its students to transfer up to 50% of the total courses from other member institutions.
- Establish a collective mechanism for the member institutions to validate and accept transfer credit from the network.
- The members of the network should participate as peers in the process
- Each member of the network should enable the learners from anywhere in the world to access all of its courses
- An interested learner should be able to take courses from any member of the network and get a degree from a particular institutions in the network
- Internship / co-op / international apprenticeship should be a mandatory component of the program
- The network would collectively take steps to promote manufacturing education. These steps may include informing the public on the scope of manufacturing and the prospects for the future, and developing outreach to K-12 students
- Elaborate partnership with industry must be at core of the networks functions. The partnership must lead constant flow of information, sponsored projects, and co-op, internship and apprenticeship assignments for students.
- On-line delivery must be part an essential of the program; A central system must enable the students to access information and enroll in courses.

8. Summary

This project was carried out as part of SME's efforts to prepare the manufacturing curricula for the year 2015 and beyond. In doing so, it presents the context in which manufacturing education must be enhanced. It includes a discussion on the role of manufacturing in the global economy, the factors affecting the scope of manufacturing, and the current efforts to revitalize manufacturing in various parts of the world. It then presents an overview of the curricular models proposed to address the needs of the manufacturing industry. As an extension of the analysis, a recommendation is made on the key aspects of any manufacturing curriculum with an emphasis on innovation and entrepreneurship. Finally, a set of strategies are proposed for the enhancement of manufacturing education. They include the creation of a flexible degree program that emphasizes learning over teaching, development of a network of academic institutions around the globe to deliver the program, use of communication technologies to provide

access to the program to anyone at anytime and anywhere in the world, and an outreach to future manufacturing professionals.

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