Incorporating Sustainability throughout the Manufacturing Engineering Technology Curriculum

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Abstract

Sustainability of the environment and the resources that humankind enjoys has become the most important issue in the recent past. Governments all over the world have been enacting laws and taking steps to reduce the degradation of the environment resulting from human activity. This paper presents, from the engineering point of view, the required steps by which sustainability can be built into systems so that it can be practiced by all concerned. In order to do this, it is necessary to incorporate sustainability concepts into all aspects of studies done by manufacturing engineers. A curriculum approach is developed in this paper based on the results obtained from a quick survey of manufacturing engineering and technologists.

1. Introduction

Manufacturing systems, though they create material wealth for humans, consume a great amount of resources while generating a lot of waste. The significant portion of the waste generated during the manufacturing processes, at the use phase, and after the end of the life of the products contributes to the degradation of the environment. These wastes include fumes and harmful gases from welding, melting, painting, coal fired or fossil fuel fired power plants, automobiles, and refinery industry; used cutting fluids, non-recyclable industrial byproducts; non-degradable plastics and synthetic fibers; non-degradable end of life products, and several others. Such harmful effects of our consumption, and its final impact on humankind, are well known ^[1, 2]. Various governments and national and international agencies have been making efforts to generate strategies and action plans to educate people and organizations to strive towards this goal as soon as possible.

In the USA, according to government estimates, manufacturing consumes about one-third of the total energy used in the country. Therefore, it is imperative that manufacturing industries strive for “Sustainable Manufacturing” on their part. Thus, it is important for manufacturing engineering technology students have a clear understanding of sustainability from the very early stage, so that they can link it with every aspect of manufacturing. This will help students not only to get a better understanding of Sustainability, but also to actually practice it in various stages of manufacturing.

Sustainable, or green, manufacturing can be broadly classified into the three major areas of a manufacturing enterprise as:

- Product Design for Sustainability
- Sustainable Manufacturing Processes
- Sustainable Manufacturing Systems (process/industrial engineering).

The various core courses taught to manufacturing engineering technology students as per the SME four pillar methodology fall into these three categories. It is therefore necessary to include the sustainable practices in each of these areas at various stages of teaching these courses. This will help the students to link the sustainable practices in a realistic manner in relation to the core concepts of manufacturing engineering technology.

The goal of this paper is to develop a comprehensive manufacturing engineering technology curriculum incorporating sustainable or green manufacturing concepts. The research approach being employed is the utilization of surveys and focus group interviews to capture the essential sustainability concepts that are required to be included in the curriculum.

The paper presents the details of developing the manufacturing engineering technology curriculum with the sustainability practices, and the model curriculum that can be implemented in two year and four year manufacturing engineering technology programs.

1.1 The Four Pillars of Manufacturing Engineering

Society of Manufacturing Engineers (SME) has recommended the Four Pillars of Manufacturing Engineering as a comprehensive approach to providing all the required knowledge for successful manufacturing engineers and technologists (Figure 1). In fact, a large number of universities have adapted their curricula to align properly with the four pillars methodology. This model is built by adopting the ABET accreditation program criteria for Manufacturing Engineering. The model will also be used to identify gaps in the current curricula so that the universities will be able to fill these gaps.

2. Survey Result and Analysis

Sustainability is a philosophy that needs to be ingrained in all people so that they will be able to incorporate it in whatever they do. To this extent, the manufacturing engineering and technology students should be provided the basics of sustainability, along with its implementation and implications, throughout their curriculum. It was therefore decided to survey academicians and industrial personnel as to what they believe should compose a sustainability-augmented manufacturing curriculum.

The following survey instruments were developed based on the objectives of the paper:

- a) A 16-question instrument to collect opinions from the faculty/academicians involved with the manufacturing engineering technology program
- b) A 6-question instrument to collect opinions from the industry representatives, especially for the representatives of the manufacturing industry.

The survey instruments are included in the appendix. The survey instruments were transformed into Survey Monkey-based survey links and sent to the target groups (faculty and industry representatives) through the following List Servers: ATMAE Professional Members, Advisory Board Members for Engineering Technology Program of The University of Texas at Brownsville; Manufacturing Engineering and Technology Program Coordinators and Faculty of Texas A&M University. A total of 30 responses from academicians and 13 responses from the industry representatives were received. There is no clear idea as to the number of suitable recipients of the survey link, based on the fact that each of the above-stated organizational groups represents multi-disciplinary professionals.

Fig. 1 Four Pillars of Manufacturing Engineering of SME Curricula 2015.

It may be mentioned at this point that this survey is not intended to test any hypothesis. As such, each survey response may be considered as the opinion of the professional based on his/her experiences, understanding, and knowledge. Since the participants of the survey are well educated professionals (faculty or industry representatives in the management category), it may safely be assumed that the participants have been able to clearly understand the descriptions of the questions. It is also assumed that the responses are from the professionals, who are either knowledgeable or have exposure to sustainability issues in manufacturing systems and of products /items/process in the manufacturing industry.

2.1 Academia Survey Findings

The questions in the Survey Instrument 1 for Academicians (see appendix) are divided into two categories:

Category 1: Questions 5.1 to 5.9 and question 7 that explored the importance given by the participants to including sustainability factors in the manufacturing based Courses. Category 2: Questions 1,2,3,4 and 6 that identified the courses or content covered by the participants under different manufacturing Engineering Technology Programs.

Discussion of Category 1 questions in Instrument 1

Table 1 presents the summary of the sustainability factors in three manufacturing subject areas that are addressed by the questions in category 1. Table 1 also includes the general contents, knowledge or concepts that may be covered under these subject areas.

Table 1: Proposed sustainability factors to be included in manufacturing based courses

Questions	
5.1 , 5.7-5.9	Manufacturing science
Sustainability factors: general environmental concerns that include energy spent, harmful emissions, and waste management	May include knowledge or content on
	- Purpose of each operation and their combinations
	- Implications of inputs and variables
	- Performances, influencing factors
	- Wastes, by products
	- Materials science
5.2,5.3, 5.6	Manufacturing Operations
Sustainability factors: General process wastes, spent energy, harmful emission while processing	May include knowledge or content on
	--Processing operations, e.g. shaping, material removal, casting
	--Assembly operations, e.g. Welding, brazing,fastening
	--Quality control, coordination, handling
5.4 and 5.5	Product Design
Sustainability factors: Design for reuse, recycle, and recovery; design for manufacturing and assembling with less energy, harmful emission, and long life	May include - design development, design for
	--Manufacturing
	--Assembly
	--Disassembly, maintenance, reliability
	--Sustainability (reuse, recycle, long life, recovery, etc.)

Table 2: Summary of survey findings on the importance provided by the responses on including sustainability contents in the courses

Subject: Manufacturing Science				
Question numbers in instrument 1	5.1	5.7	5.8	5.9
Average Response Rating to include sustainability factors	4.26	4.3	4.26	4.22
After taking out one outlier	4.4	4.45	4.41	4.36
Subject: Manufacturing operations				

Questions in instrument 1	5.2	5.3	5.6
Average Response Rating to include sustainability factors	4.5	4.7	4.27
After taking out one outlier	4.67	4.86	4.6
Subject: Product Design			
Questions in instrument 1	5.4	5.5	
Average Response Rating to include sustainability factors	4.91	4.81	
After taking out one outlier	5.1	5	

Table 2 summarizes the survey findings in terms of average rating /importance provided by the responses. According to Table 2, average importance rating to include one or more sustainability factor in each of the three subjects is more than 4.0 out of maximum possible rating 6 based on average 23 responses out of 30 responses. Survey responses showed one outlier in each group where rating is 1 out of 1 to 6. If we segregate outlier response, rating in each group increases as may be seen in Table 2. The question descriptions (see the question number 5) defined the ratings as the importance to be given by a participant. Based on Table 2 importance given by the responses on including sustainability factors in design based courses are as high as 5 out of 6, if we segregate the outlier. In the case of Manufacturing Operations, opinions to include sustainability factors are uniform for each question of 5.2, 5.3, and 5.6 (Tables 1 and 2).

Faculty /academia feedback on each of the above three groups establishes the importance of including sustainability issues in manufacturing engineering courses.

Question number 7 of Category 1 was an open ended question that asked the participants to provide suggestions to improve sustainability considerations in the course curriculum. Table 3 lists suggestions included by 7 participants out of 30:

Table 3: Suggestions to improve sustainability considerations in the Manufacturing Engineering Curriculum

<ol style="list-style-type: none"> Clearly an element, but first must deliver the basics and economics. Economic, Green and Sustainability as well as Ethics are very important, but not without proper basics of the manufacturing science. Otherwise, it is politically correct but not very useful. These topics need to be incorporated into popular textbooks. Student Exchange Program with other countries. We should have a general sustainability course that will address sustainability issues in manufacturing and non-manufacturing process. Include sustainability considerations in all manufacturing/related course material. Has to include some sort of Introduction and how it applies. Has to be separated from political terminology as some students feel that that topic is political, e.g. not use "green design" which is common in Europe, but use "Design for environmental compliance"

The suggestions are self-explanatory and each one is very important in its own right. We shall visit these while coming up with the outline of the curriculum.

Discussion of Category 2 questions in instrument 1

Questions 1, 2, 3, and 4 provided the context of the responses summarized in Table 2.

Table 4, generated from the Question 1 responses, summarizes the courses that are taught by the participants along with their program affiliations. Table 4 includes most of the manufacturing engineering technology courses that are taught in the universities under the listed programs.

We may also observe contents that are covered in these courses in Table 5. Considering responses in Tables 4 and 5 it is evident that the responses rating in Table 2 are reasonable and informed recommendations by the knowledgeable representatives of the society. This is because, the participants have been involved in teaching the subjects and they expressed what they found important based on their knowledge in the field and their expectations from the graduates.

Table 4: Survey response on the manufacturing engineering technology courses taught by the participant faculty

<u>Manufacturing related courses</u>	<u>B.S. Mfg Engr</u>	<u>BS Mfg Tech</u>	<u>B.S. Mfg Eng Tech</u>	<u>Any of them</u>
1. Manufacturing Processes	14.3%	23.8%	52.4%	19%
2. Metal cutting theory/ Machine tools	8.3%	16.7%	41.7%	33.3%
3. Engineering materials/ Materials Science/Metallurgy	21.4%	21.4%	35.7%	21.4%
4. Machine design or design of machine tools	14.3%	14.3%	28.6%	42.9%
5. Product design	7.7%	23.1%	46.2%	30.8%
6. Manufacturing Tooling Design	0	12.5%	50.0%	37.5%
7. Production planning and control	17.6%	2.5%	52.9%	17.6%
8. Lean Manufacturing	11.8%	29.4%	52.9%	23.5%
9. Manufacturing Process and services design	26.4%	20.0%	53.3%	20.0%
10. Quality control	16.7%	33.3%	44.4%	22.2%
11. Basic Electronics/ Mechatronics	13.3%	20.0%	40.0%	26.7%
12. Robotics and Automation	14.3%	14.3%	35.7%	35.7%
13. Computer Integrated manufacturing	23.1%	15.4%	38.5%	23.1%
14. Project and Organizational Management	16.7%	25.0%	50.0%	33.3%
15. Capstone Projects in manufacturing / Senior Design Projects	21.4%	14.3%	50.4%	21.4%
16. Sustainable manufacturing	22.2%	33.3%	11.1%	44.4%

Table 5: The manufacturing engineering technology contents covered by the participating faculty

<u>Manufacturing related courses</u>	<u>B.S. Mfg. Engr.</u>	<u>B.S. in Mfg. Tec</u>	<u>B.S. Mfg. Eng. Tec.</u>	<u>Any of them</u>
1. It is a design based course	12.5%	33.3%	43.8%	18.8%
2. It is a combination of lab and theory based course	21.7%	26.1%	43.5%	21.7%
3. It covers general idea on manufacturing process	14.3%	33.3%	47.6%	14.3%
4. It covers property of materials and manufacturing of materials	6.3%	37.5%	31.3%	25.0%
5. It covers computer integration	21.1%	21.1%	42.1%	21.1%
6. It covers application of microprocessors, controls	25.0%	8.3%	41.7%	25%

in manufacturing				
7. It outlines sustainability consideration in manufacturing	0	25.0%	41.7%	3.3%

2.2 Industry Representatives Survey Findings

In question 1 of Instrument 2 professionals from industry provided their opinions on including select sustainability content as shown in Table 6 in the course curriculum.

Table 6: Opinions of industry representatives to include sustainability contents in the curriculum

Sustainability Contents	Response percentage
Government Regulations applicable to industries	69.2%
Idea on Green Manufacturing and sustainable practices	61.5%
ISO 14000	7.7%
LCA considerations for products	7.7%

Industry representatives attached very high importance (69.2%) of educating manufacturing engineering technology graduates on government regulations and the idea of green manufacturing and sustainable practices (61.5%) as may be observed in Table 6. Government regulations address several environmental issues, including disposal and processing of waste to protect the environment; controlling of harmful emissions to protect employees, community, and resources in and around the industry. Ideas on green and sustainable practices cover most of the contents that a responsible citizen or industry representative should be aware of. This feedback from the industry representatives echoed the same recommendations as the academicians discussed above.

Table 7 describes the opinions of industry professional on select collaborative efforts of industry and university in educating the manufacturing engineering technology graduates. Based on the importance as evidenced by the % of responses, industry professionals provided comprehensive recommendations for effective collaboration on educating graduates from technology programs. The feedback provided highest importance (45.5%) to conduct studies in identifying the industrial processes to apply sustainability practices, next importance given to educate the students on ecological requirements for the processes (36.4%), and working on sustainability based projects.

Table 7: Opinions of industry professionals on select industry-university collaborative efforts

Collaborative efforts to educate graduates on sustainability	Response percentage
Conducting study in the industry to find out points/processes for applying green or sustainable practices	45.5%
Educating students on ecological requirements for production and services	36.4%
Taking sustainability based projects	36.4%
Bringing sustainability experts as guest lecturers in the classes	27.3%
Establishing Labs for LCA of products	0.0%

Table 8 summarizes the opinions of industry experts on select benefits of including sustainability issues in the manufacturing engineering curriculum. Based on the average response rate (more than 4 out of highest 6), the feedback from industry experts clearly establishes strong support/agreements of industry professionals on these selective benefits of such inclusion.

Table 8: Opinions of industry professionals on select benefits

Select benefits	Average response rating
Industry and society will be benefited	4.83
Graduates will be innovative for improving processes	4.58
Improvement of employability	4.08
Note: The response ratings do not include one outlier that rated 1	

Based on the survey feedback analysis, it is evident that the participating academicians and industry experts provided high importance on the incorporation of sustainability in the manufacturing engineering technology curriculum. In addition, the survey attached high importance on the inclusion of select sustainability /ecological contents and collaborative efforts in the curriculum. This survey feedback may not be considered for investment decision in establishing sustainability practices, but it may be considered as a crucial recommendation to motivate universities to include sustainability contents in their curriculum.

3. Proposed Curriculum

As can be seen from the survey, the incorporation of sustainability concepts into all the curriculum modules is important. Before they can be incorporated, it is also important for the students to have a complete knowledge of the implications of sustainability in terms of its ramifications, tools to measure the implications, and the government laws that need to be followed. This course needs to be provided at the very early stage of the curriculum before the students can get deeper into the curriculum modules of manufacturing engineering/technology.

3.1 Sustainability Competencies

As discussed earlier, it is necessary to incorporate the sustainability requirements throughout the curriculum rather than in a single specific course. In that manner the student will have a better understanding of the implications and the way these can be practiced. Sustainability course content framework with clusters/modules might be used to develop a new course or used in the outcomes of several existing manufacturing related courses.

The sustainability competency clusters are identified from the recent literature ^[3, 4, 5, and 10] and presented in the first column of the Table 9. These competency clusters then link to the three main sustainability modules proposed in the survey, namely, manufacturing sciences, manufacturing operations, and product design, to arrive at the topic areas in sustainability. These topic areas might be used to develop new courses or can be used in the existing courses to spread the sustainability competencies throughout the manufacturing engineering technology curriculum.

Table 9: Linking the Sustainability competency clusters with the sustainability manufacturing modules

Sustainability Competency Clusters	Proposed sustainability modules to be included in Manufacturing based courses		
	Manufacturing Science	Manufacturing Operations	Product Design
I Introduction to Sustainability	Topic Areas: What is sustainable Manufacturing? Carbon foot print calculation Energy estimation Waste generation	Topic Areas: Energy calculations Waste estimation.	Topic Areas: Case study
II Environmental Ethics & Social Development	Topic Areas: Health and the Environment		
III Ecology & Nature		Topic Areas: Greenhouse gas emission, carbon cycle	
IV Environmental Challenges & Sustainable Solutions		Topic Areas: Green energy solutions, low carbon fuel, sustainable process development/resources	
V Sustainable Design & Transportation			Topic Areas: Transportation – environment friendly automobile design using alternate fuels
VI Balancing Ecology & Economics		Topic Areas: Optimization methods	Topic Areas: Conservation, environmental friendly product design
VII Sustainable Actions		Topic Areas: Energy audit, action projects and process development	

3.2 Manufacturing Competency clusters

A set of competencies recommended in the literature ^[6, 7, 8, 9, and 11] is grouped to reflect in the corresponding manufacturing courses shown in Table 10. The competencies, namely systems thinking, anticipatory, normative, strategic, and interpersonal, are further developed into the subcategories of competencies and presented in the second row of Table 10. These competencies might be included in the new or existing manufacturing engineering and technology courses as shown in Table 10. The competencies and outcomes can be achieved in the corresponding manufacturing related courses at three different levels, namely introduce, develop, and apply. Any of the competencies can be introduced first in the 1000 or 2000 level courses and then developed in 3000 level courses. The final outcome of the competencies can be delivered and assessed in the corresponding 3000 or 4000 level courses in the form of applications. The pedagogical hierarchy of sustainability studies, namely introduce, develop, and apply, is linked to the corresponding manufacturing courses and presented in Table 10.

Table 10: Manufacturing curriculum map matrix: A set of competencies in manufacturing sustainability education, linking basic manufacturing courses.

Manufacturing Courses	Systems Thinking Competence	Anticipatory Competence	Normative Competence	Strategic Competence	Interpersonal Competence
	Variables, sub-systems, structures, functions Feedback loops, cause effect chains Local to global Society, environment, economy, technology People and social systems	Concepts of risk, precaution	Sustainability of current or future states Sustainability Principles Concepts of responsibility, safety Concepts of risk, damage Ethical concepts	Strategies Feasibility, efficiency	Dynamics of collaboration Team success, failures Concepts of leadership
Introduction to Sustainability	Introduce	Introduce	Introduce	Introduce	Introduce

Engineering Materials	Introduce	Introduce	Introduce	Introduce	Introduce
Manufacturing Process Technologies	Reinforce	Reinforce	Reinforce	Reinforce	Reinforce
Design Graphics	Introduce	Introduce	Reinforce	Introduce	Introduce
CNC/CAM/CIM	Reinforce	Reinforce	Reinforce	Reinforce	Reinforce
Product and Process Design	Apply	Reinforce	Apply	Reinforce	Apply
Manufacturing Process Planning	Apply	Apply	Apply	Reinforce	Apply
Robotics and Automation	Reinforce	Reinforce	Reinforce	Reinforce	Apply
Quality Control	Apply	Reinforce	Reinforce	Apply	Apply
Senior Design	Apply	Apply	Apply	Apply	Apply

3.3 Sustainability curriculum development

Curriculum development matrix linking the core competencies of sustainability with the basic courses in manufacturing is presented in Table 11. The details of the topic areas that can be covered in the basic manufacturing courses in the curriculum are developed based on the framework of the sustainability curriculum discussed in the previous sections. The possible learning outcomes are matched to the topic areas to clearly identify the level of the manufacturing courses that will deliver the sustainability concepts.

Table 11 clearly identifies the possible topic areas along with the learning outcomes presented in each of the manufacturing related courses in the curriculum. The recommendation of the spread of sustainability concepts throughout the manufacturing curriculum is not prescriptive in nature; rather it should be taken as a tool with which to develop a curriculum that will suit the individual manufacturing engineering and technology programs.

Table 11: Curriculum development matrix

Year of Study	Basic Manufacturing Courses	Topic Areas	Possible Learning outcomes
1 st Year	Introduction to Sustainability	Society, environment, economy, technology People and social systems	<ul style="list-style-type: none"> • Explain how the concept of sustainability applies at a local, regional, national, and global level • Explain how systems theory applies to sustainable manufacturing • Calculate the carbon footprints of various industries • Analyze the effect of various manufacturing processes
	Design Graphics	Sustainable product design principles	<ul style="list-style-type: none"> • Practice Product design using the Parametric design approach • Redesign products by minimizing the effect of tolerance accumulation for quantity production
2 nd Year	Engineering Materials	Hazardous Materials Materials for Green building Design Recyclable materials Alternate materials for Green product and process design	<ul style="list-style-type: none"> • Explain the environmental mitigation using alternate material selection • Calculate the energy and material cost conservation by the selection of appropriate materials
	Manufacturing Process Technologies	Concepts of recyclability and reuse Concepts of remanufacturing Energy	<p>Explain the concepts of recyclability and reuse</p> <p>Examples and case studies of remanufacturing</p> <p>Select the manufacturing process parameters for minimum energy</p>

		conservation through judicial process selection Minimum Quantity Lubrication	consumption Explain the concept of Minimum Quantity Lubrication
	CNC/CAM/CIM/FMS	Energy conservation through judicial process selection Concept of Zero inventory Design for interchangeability Unmanned shifts Fully Automated factory Virtual Manufacturing	Demonstrate Energy conservation through judicial process selection Explain the Concept of Zero inventory Show examples of Design for interchangeability Explain Unmanned shifts Explain Fully Automated factory What is Virtual Manufacturing?
3rd Year	Quality Control	Six Sigma Lean manufacturing Fail safe methods (Poka Yoke)	Problems in - Six Sigma Lean manufacturing Fail safe methods (Poka Yoke)
	Product and Process Design	Robust Design Taguchi methods Design of experiments Design for Manufacturing	Examples of DFM Explain Robust Design Examples of Taguchi methods Problems in Design of experiments Problems in Design for

		concepts	Manufacturing concepts
4th Year	Manufacturing Process Planning	Kanban Concepts Design concepts of Visual Factory	Explain the Kanban with calculations Design a of Visual Factory with examples
	Robotics and Automation	Concepts of Design for assembly Boothroyd and Dewhurst technique for calculating automated assembly time	Explain the Concepts of Design for assembly Calculate assembly time using the Boothroyd and Dewhurst technique
	Senior Design	Application of all sustainability concepts in the senior project design	Demonstration of sustainability concepts in the product and process design

4. Conclusions

The view that sustainability is an important subject that needs to be considered in all aspects of manufacturing has been stressed by a number of researchers and educators throughout the world. The authors conducted a survey of personnel who are involved in manufacturing, both academicians and industrial professionals. Most of the faculty responding to the survey felt that students would greatly benefit from the addition of sustainability course content addressing all areas of manufacturing, including design, operation, and processes. These faculty also indicated that they already include some aspects of sustainability in the content that they teach. The industry professionals likewise stressed the importance of sustainability; among the feedback they provided was that the inclusion of details about ISO 14000 and LCA at all levels would greatly benefit engineers and technologists.

A framework for the incorporation of sustainability, based on the above responses, is presented in this paper. The framework introduces students to the various conceptual tools that they will use to understand the environmental consequences of different inputs that go into manufacturing. Then these identified concepts are properly distributed within the various courses on manufacturing science, manufacturing operations, and manufacturing design. The framework is deliberately kept open so that schools that are so interested can further adjust the structure to develop a curriculum that is better suited to their available resources.

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