Curriculum design for sustainability of globally integrated manufacturing

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Curriculum design for sustainability of global integrated macro-nano manufacturing

Abstract:

Integrating the scalable nanotechnologies into existing industrial systems is highly beneficial for improving the quality, capability and performance of almost all kinds of industrial sectors. However, significant sustainability issues and challenges exist in the practical integration and subsequent operations of the integrated macro-nano industrial systems, including increased waste generations, extra energy consumptions, additional greenhouse gas emissions, novel nano-particle emissions for occupational and public exposure, etc.

This paper will analyze which competence domains, a curriculum towards sustainable manufacturing should have and how a certificate program in "Sustainable Manufacturing" can be accomplished. This curriculum design is based on the experience of creating and teaching new graduate level courses "Sustainable Manufacturing" at Texas Tech University and "Energy Efficiency and Industrial Sustainability" at University of Wisconsin Milwaukee. All segments of society must be educated to understand, environmental, economic and social connections within manufacturing systems engineering to facilitate sustainability. The innovations in technology and management play a fundamental role in solving the global challenge in economic development, while simultaneously preserving life, conserving natural resources and creation of social justice. This pilot study could be a pioneer for further countries in the world such as China, Indian, Brazil and Saudi Arabia, which would be interested in implementing sustainable manufacturing.

Keywords:

Engineering education, curriculum design, sustainable manufacturing

Introduction

In today's competitive manufacturing day and age, it is common for a traditional manufacturer or entrepreneur to try and implement the use a nano-manufactured product or material, to create a distinct competitive advantage for themselves. If we were to consider an electronics manufacturer who desires to use nanomaterials to create parts that can actively disassemble using shape-memory polymers[1], or an entrepreneur who would like to investigate the incorporation of nanomaterials to create coatings to enhance the durability of compressed earth block (CEB) structures[2], we need to understand how such knowledge can be quickly located, assessed, and applied to create innovative products, while meeting the triple criteria (environment, economy, and society) of sustainability. Sustainability performance has gained more attention in the past few decades. Therefore not only economic performance is the priority, but also the environmental and social performance are critical for the competitive manufacturer or entrepreneur.

Nano-scale manufacturing, with its superior capability to overcome technological barriers, can greatly enhance product quality, yield and performance to better meet human needs, and will facilitate both industrial and social progress. Recently, various nano-manufacturing technologies have been under rapid development toward large-scale industrial applications. Currently more than 1317 nanotechnology-based consumer products have been made available in the market through the integration of conventional and nano-manufacturing technologies[3]. As a conservative estimate, the global market for nanotechnologies is increasing by 25% annually and will reach beyond $3000 billion by 2020[4]. Nevertheless there need to be better mechanisms to connect entrepreneurs and industry with the latest research in sustainable nano-manufacturing and best practices for integrating it into the global “macro” manufacturing industry.

Innovation is an activity with broader scope than invention—including not only the implementation of a novel idea, but also the creation of a competitive advantage as well as its acceptance. “Invention is the first occurrence of an idea for a new product or process”[5], while innovation “refer[s] to the entire process by which technological change is deployed in commercial products”[6]. Knowledge-based mechanisms for integrating nano-manufacturing into the global “macro” manufacturing industry, if developed, will broaden and diffuse participation in innovation processes to include individuals without prior engineering and scientific backgrounds in nanomanufacturing[7].

However, the sustainability performance of nano-manufacturing is more concerning than that of conventional macro-manufacturing[8]. Sustainability as applied to engineering design is perhaps best understood in terms of energy resources, environmental issues, economic factors, and social impact[9]. The energy intensities of nano-scale manufacturing are usually 4~6 orders of magnitude higher than those of conventional macro-manufacturing technologies[10]. Also, toxic chemicals are heavily used in nano-scale manufacturing for cleaning, etching, reacting, etc[11]. Integrating nano-manufacturing into conventional macro-manufacturing systems will largely increase the energy consumption, greenhouse gas emissions, toxic chemical releases, and solid waste generation of manufacturing industry. Moreover, nano-manufacturing technologies produce nano-material wastes and nano-particle emissions that have been shown to produce more toxic effects on animals than bulk materials due to the small particle size and large surface area-to-mass ratio[12]. In short, impulsive adoption of nano-manufacturing into large-scale industrial productions may pose a severe risk to human health and result in adverse environmental impacts.

While the integration of macro-nano manufacturing has begun, and global application of such manufacturing systems are expected to expand into a broad array of industrial sectors in the future, the scientific investigations of the sustainability of integrated macro-nano manufacturing, as shown schematically in Figure 1, have not yet been conducted. A framework of holistic sustainability issues of global integrated macro-nano manufacturing industry is developed in Figure 1. The sustainability considers economic impact, environmental impact, social impact and human health impact by integrating the conventional macro-manufacturing and emerging nano-manufacturing at the same time. A number of questions still remain unanswered, including: what are the levels of environmental impacts that integrated macro-nano manufacturing will generate during the integration and subsequent operating processes? How can the environmental performance of the integrated macro-nano manufacturing be comprehensively evaluated? Further, considering the health concerns related to nano-materials, what measures need to be developed for safe handling of materials/wastes/emissions from integrated macro-nano manufacturing systems?

What strategies do industries need to take to minimize environmental impacts of integrated macro-nano manufacturing?

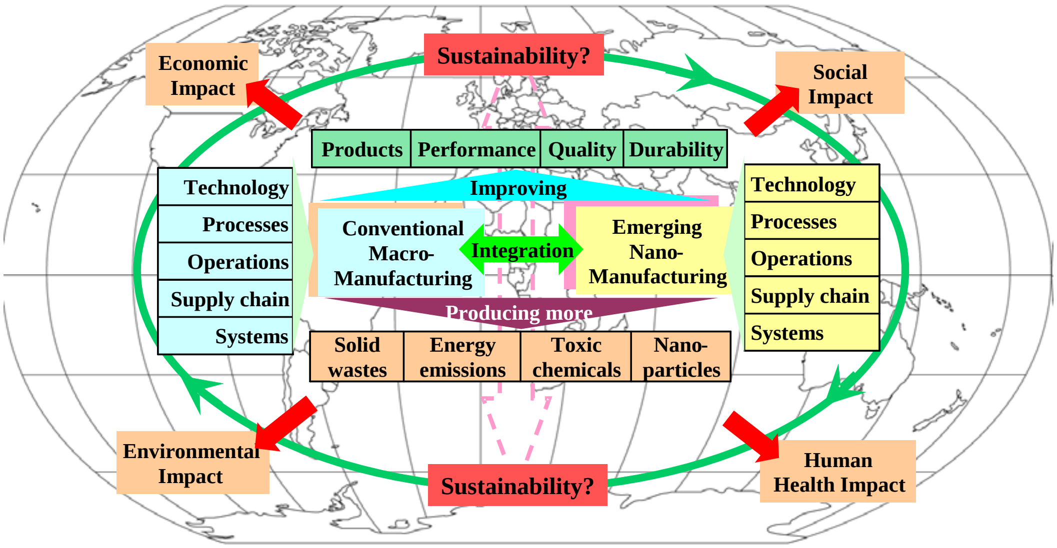

Figure 1. Holistic sustainability issues of global integrated macro-nano manufacturing industry

This paper analyzes which competence domains, a curriculum towards sustainable manufacturing should have and how a certificate program in "Sustainable Manufacturing" can be accomplished. This curriculum design is based on the experience of creating and teaching new graduate level courses "Sustainable Manufacturing" at Texas Tech University which has been offered since Summer 2010 and "Energy Efficiency and Industrial Sustainability" at University of Wisconsin Milwaukee which has been offered from Fall 2012. This paper seeks to develop an intellectual framework for nanomanufacturing as integrated into the global "macro" manufacturing industry. As a unifying focus, this work will model the connections between the nano and macro-level manufacturing objectives across the three domains of design, process, and systems—with the goal of creating a framework to integrate the consideration of sustainability issues related to nanomanufacturing.

Framework

The proposed graduate course will combine analytical, computational, and experimental activities and focus on objectives and issues that need to be addressed for successful integration of nanomaterials into sustainable, global "macro" manufacturing practices. The objective of this course is to conduct a systematic investigations into the integration of macro-nano manufacturing processes. It is designed for the graduate level students. The prerequisite is manufacturing processes related course (upper level undergraduate course or graduate level course) and nanomanufacturing or nanomaterial related course (upper level undergraduate course or graduate level course). This course could be conducted for Master or Ph.D. degree in major of Manufacturing Engineering, Mechanical Engineering, Industrial Engineering, or Material Engineering. The framework developed will be organized around the three themes of design, process, and systems, as shown in Figure 2:

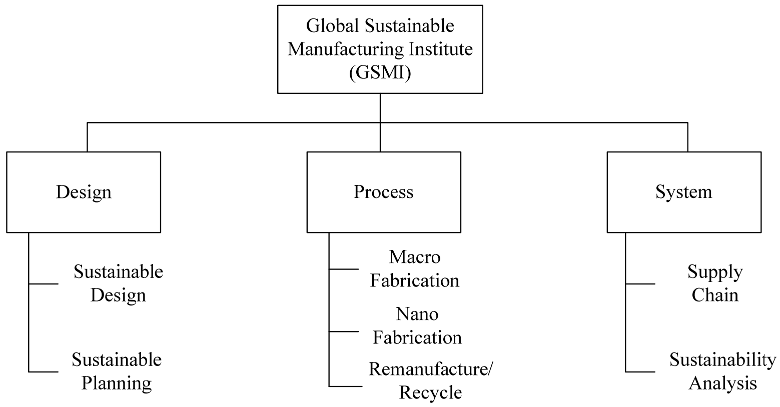

Figure 2: Organizational chart.

This graduate course will conduct systematic investigations into the integration of macro-nano manufacturing processes and to develop manufacturing-knowledge-based methods and tools for mathematical modeling, experimental validation, and strategic improvement of the sustainability performance of the global, integrated macro-nano manufacturing industry. This course will be developed with an overall objective to understand and improve the sustainability performance of integrated macro-nano manufacturing from a systematic perspective and to support the sustainable practices of the manufacturing industry in integrating macro and nano-scale manufacturing technologies. Design, process and systems are the most three essential elements for a sustainable macro-nano manufacturing. Design can cover sustainable design and planning, which is the first and important step leading to a sustainable manufacturing. Process includes all the related manufacturing processes: macro fabrication, nano fabrication and end-of-life strategies (reduce, remanufacture, recycle). After design and manufacturing of products, it is also critical to implement the supply chain optimization and sustainability analysis, which would be the system. As mentioned above, this course would be developed around the three themes that inherently support each other and together form a hierarchical sustainability management system:

Design (Sustainable Design and Planning)

The theme of sustainable design will integrate design-assistant tools (such as GaBi DfX [13], and Sustainable Materials Assistant for Autodesk Inventor[14]) and process planning algorithms for sustainable integration of conventional macro- and scalable nano-manufacturing technologies. These tools and algorithms will be developed based on state-of-the-art "Design for Sustainability" approaches and computer-aid process planning techniques. These tools and algorithms, when successfully used in the early stages of manufacturing system design and process planning, can implement the sustainability goals with the lowest cost but the highest effectiveness. The theme of sustainable planning will establish a computational model for the integrated macro-nano manufacturing industry through integrating intelligent data mining techniques, natural language processing, and machine-learning techniques to characterize the integrated manufacturing process/system parameters.

Process (Macro Fabrication, Nano Fabrication, and Reduce/Remanufacture/Recycle)

The theme of nanofabrication will study nano-wastes and nano-particle emissions mechanism from the integrated macro-nano manufacturing industry, develop mathematical models to simulate and predict the nano-particle emissions, and characterize the potential risks of nano-waste exposure to both occupational and public health. This task will be accomplished through a systematic approach involving both theoretical modeling and experimental investigations to track nano-material flows, measure nano-particle emissions, and identify potential exposure routes and pathways for both occupational and public health. The theoretical modeling will be conducted by using chemistry-based lattice modeling, material flow analysis and risk characterization techniques. The theme of remanufacturing/recycling will develop strategies and techniques to reducing wastes/emissions, re-manufacturing of defective products, recycling and recovering of valuable materials, etc. This task will be conducted with both systematic modeling and experimental testing. The modeling will focus on sustaining the operations and throughput of the integrated macro-nano manufacturing system at the lowest cost level; the experimental investigations will be performed on handling and processing the waste materials, defective products, and servicing components of the integrated macro-nano manufacturing system with the minimum health risks.

System (Supply Chain and Sustainability Analysis)

This theme will assess the overall sustainability performance of the integrated macro-nano manufacturing, considering both conventional environmental emissions and novel nano-particle emissions. Comprehensive sustainability analysis metrics and tools will be developed for assessing the integrated macro-nano manufacturing systems, to support decision-making and system optimization for overall sustainability improvement. In this research, agent-based material flow analysis, energy flow analysis, and life cycle inventory analysis methods will be employed to characterize the process-based environmental emission inventory; cost benefit analysis approach will be used to evaluate the economic performance of the macro-nano technology integration; such life cycle impact analysis methods as resources depletion, global warming, human toxicity, eco-toxicity, etc., will be employed for environmental impact characterization. As part of the systems approach to this course, the curriculum will also include a focus on evaluating what the risks are as far as the supply chain and the sustainability aspects of the project are concerned.

Pedagogical Approach

Assignments for this course will be carried out based on a Problem-Based Learning (PBL) pedagogical approach that will be implemented in an integrated learning environment that is learner-centered, knowledge-centered, assessment-centered, and community-centered. PBL, developed in the 1970s, has gained increasing popularity in higher education[15]. Its desirable outcome, compared to that of traditional modes of teaching, is that students develop deep-learning approaches that enable them to engage in lifelong learning. Other advantages include increased retention of knowledge, development of integrated knowledge, and increased motivation[16]. The integrated learning environment is designed based on principles of learning derived from a diverse body of research[17]. Specifically, in a learner-centered environment, teachers must pay close attention to the knowledge, skills, and attitudes that students bring into the classroom. In a knowledge-centered environment, attention must be given to what is taught, why it is taught, and what competence looks like. In an assessment-centered environment, formative assessments (designed to make students' thinking visible to both teachers and students) are essential to monitor learning progress. Finally, learning is influenced in fundamental ways by the context in which it takes place; thus, a community-entered approach requires connections to the outside world that supports core learning values. These four perspectives should be conceptualized as a system of interconnected components that mutually support one another[18].

The implementation strategy will be implemented as follows:

1) Assignments will require mastering key concepts identified for each theme of design, process, and systems and will be developed based on real-world cases in global settings from industries such as semiconductor and automotive manufacturing. The students will be assigned to work on specific assignments, so they can use the key concepts in different contexts. As such, students are more likely to abstract the relevant features and develop a flexible representation of the subject matter.
2) The students will be required to produce periodic reports so the instructor(s) can use "diagnostic teaching" techniques to ensure student learning is progressing in the right direction. This formative assessment technique is designed to make students' thinking visible to both teachers and students. This learner-centered approach can help students more effectively build a formal understanding of the subject matter. As well, this assessment-centered approach is essential to monitor learning progress and ensure that students master the subject matters.
3) After students complete their projects, solutions will be evaluated by experts (including industry experts), so they can learn the strategies used by subject matter experts. This knowledge-centered approach can help students get exposed to real world applications versus mere textbook problems.
4) While working on a project, students will be assigned to teams, and they will be encouraged not only to collaborate with other teams sharing the same focus, but to seek out help from those focusing on other themes. The real-world cases and participation of experts from industry will allow students to establish a clear connection to the real world, feeling their project make a visible contribution to society. This community-centered approach is an important motivation factor for students to pursue entrepreneurial activities and engage in lifelong learning.

Education Plan

The goal of the proposed course is to produce the next generation leaders in sustainable manufacturing that have the following characteristics:

1) Experts in sustainable manufacturing technologies including design (design tool and process planning), process (nano and macro fabrication, waste reduction), and system integration (supply chain and sustainability analysis).
2) Highly motivated individuals that are passionate in creating a sustainable society for future generations.
3) Innovative and enterprising individuals who are interested in both research and commercialization of sustainable manufacturing technologies.
4) Interdisciplinary minded and life-long learners who are dedicated to continuous innovation to advance the field of sustainable manufacturing.

The course will include stand-alone modules on sustainable manufacturing for use in existing courses and curricula. These modules will be used in several existing courses to achieve broad impact on undergraduate students through senior design projects, freshman design courses, and graduate electives[19, 20].The module materials will be published on the program website for use. Additionally the program will run several graduate-level seminar-style courses through web-enabled technology that can be used by the broad pool of graduate students at the institutions.

Expected Findings

This paper develops an intellectual framework for nanomanufacturing as integrated into the global "macro" manufacturing industry, which is based on the experience of creating and teaching new graduate level at two universities. This work models the connections between the nano and macro-level manufacturing objectives across the three domains of design, process, and systems—with the goal of creating a framework to integrate the consideration of sustainability issues related to nanomanufacturing. This course will complement existing educational and outreach efforts in the area of innovative and sustainable design. Sustainability is attracting the attention of students around the world, and numerous anecdotal reports and a recent study, suggest that sustainability curricula increase the recruitment and retention of women and underrepresented groups. This pilot study could be a pioneer for further countries in the world such as China, India, Brazil and Saudi Arabia, which would be interested in implementing sustainable manufacturing.

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