Enhancement of Engineering Design and Manufacturing Courses through the Acquisition of 3D Printers for Rapid Prototyping

Ghanashyam Joshi, Samuel Ibekwe, Patrick Mensah, and Habib Mohamadian
Mechanical Engineering Department
Southern University, Baton Rouge, LA 70813

Abstract

There is a growing need for improvement in manufacturing agility, product quality, reliability, and cost reduction in the global marketplace. The effective mechanism of achieving substantial improvements in design-manufacturing process is by including multiple viewpoints concurrently in the virtual prototyping and 3D rapid prototyping loops. The 3D solid models printed on the commercially available 3D printers provide the outstanding ability of "toying with" ideas and innovations. It contributes positively to the shortening of design-manufacturing cycle by providing the hands-on feel of function, fit, and suitability of finished product to the intended application. It is also possible to make scaled down design prototypes for laboratory testing and evaluations. A concept modeler that will strengthen the design-manufacturing backbone of the existing curriculum by the application of 3D printing technology is laid out here. Student learning through improved attention, interest, and overall stimulation of design and manufacturing education are predictable outcomes. The new technology will also enable us to attract industry partnership that will be mutually beneficial with regards to training, demonstration, and innovations in product design. This paper describes a snapshot of our curriculum enhancement plan and evolving ideas for industrial partnership.

I. Introduction

In keeping up with the new millennium and in preparation for the accreditation team visit to the department in Fall 2003, the college has vigorously pursued the strategic initiative to equip our laboratories with state of the art instruments for high quality and effective instruction and research activities, necessary for accredited undergraduate engineering education. The department moved into its new ultra-modern Engineering building complex in the Spring 2002. Sixty percent of the 117,000 square feet area of this building has been dedicated to laboratories. Through industry sponsored laboratory adoption initiative and persistent faculty effort in attracting sponsored curriculum enhancement focused research, the department has started to equip laboratories in the new building with the latest machines and instruments. The key focus will be to include application of rapid prototyping machines, data acquisition and analysis, and CAD/CAM/CAE all through the curriculum. The driving concept is that the students should be able to experience the complete design-manufacturing-engineering picture, many times during their courses of studies. Engineering educators recognize that during freshman year, the design-manufacturing experience that students have can be a strong magnet that will retain and affirm their interest in engineering education. A means for them to realize the product of their design will provide them the gratification of quick success and further renew their resolve in their prospective profession. This benefit will continue throughout the course of their study as 3-D printing rapid prototyping will encourage creativity and enhance the design-manufacturing experience across the curriculum. An experience that is a requirement in the capstone design courses, and one greatly valued in the job market. The proposed curriculum enhancement plan based on the application of 3D printing technology in the curriculum will now be described.

II. Existing relevant curriculum: Need for 3-D printers

The design and manufacturing education in our curriculum begins with a freshman course titled Introduction to Engineering and Technology (MeEn 120), that introduces students to design process, methodology, and computer aided drafting using SDRC I-DEAS software[1]. This course requires the completion of student team project comprising of CAD model, design journal, and physical model. The Freshman Engineering (CiEn 130) course offered in second semester further develops computer and technical communication skills. The second year course offerings include 'Manufacturing Processes' (MeEn 201) where manufacturing methods, theory and practice, economics and quality issues, and importance of knowing 'manufacturing' during the design process are introduced. The course has accompanying manufacturing practice laboratory where students build models using casting and machining processes. Another second year class is 'Introduction to Computer Aided Drafting and Design ,CADD' (MeEn 252). Students gain experience in drawing intricate machine parts, working drawings and assembly drawings. The exercise ends up in printing CAD drawings, which may not be manufactured due to unavailability of 3D printers in the laboratories. The design-manufacturing courses offered in third year curriculum include Mechanics of Machines (MeEn 350) and Machine Design (MeEn 365). The impact of these courses can be multiplied by the use of working models to demonstrate the key engineering concepts. Senior Design I & II (MeEn 450 and 451) are the capstone design courses offered in the senior year, where industry sponsored projects are assigned to student teams. Students and faculty are bothered by the problems that often crop up in some aspect of the implementation stage of design process, which is in the building of a working prototype. The lack of workshop skills, unavailability of tools and machines dampens the creativity spirit of "toying with" the concepts.

The lingering abstractness that students often struggle with as they study engineering stands in the way of their connecting theory with practical applications. In fact research suggests that effective education is built on several key components[2-8]: hands-on investigative materials, active cognitive involvement (inquiry) that promotes higher-level thinking skills, problem solving, group work and cooperative experiences that stimulate active involvement, and authentic task oriented assessment, which stimulates students to think through problems instead of looking for "correct answers to factual questions". Students must be able to deal with "open-ended problems" which do not have one single solution and while the solution may be useful, the experience gained in reaching those decisions and "toying with" those concepts is much more important. The implementation of 3-D printers for rapid prototyping will help bridge the gaps among theory, concepts, creativity, and practice. 3-D printers manufacture inexpensive 3-D models from CAD model file, in much the same way, as a desktop inkjet printer will print on paper. The proposed curriculum plan for the application of 3-D printing will now be presented.

III. Implementation of 3-D printing: Proposed curriculum plan

In view of the critical need of 3-D printing technology in our curriculum, mechanical engineering department has acquired one Thermo-Jet-Modeler[2] and one SLA-250 rapid prototyping machine[2] from the 3D-Systems Company. The proposed equipment is capable of manufacturing plastic prototypes with maximum permissible dimensions of 10-in. by 8-in. by 8-in. and with approximate material cost of about $20-$30 per prototype. The installation and training on the equipment is already in progress. The implementation plan is to utilize these machines in the selected courses as soon as possible.

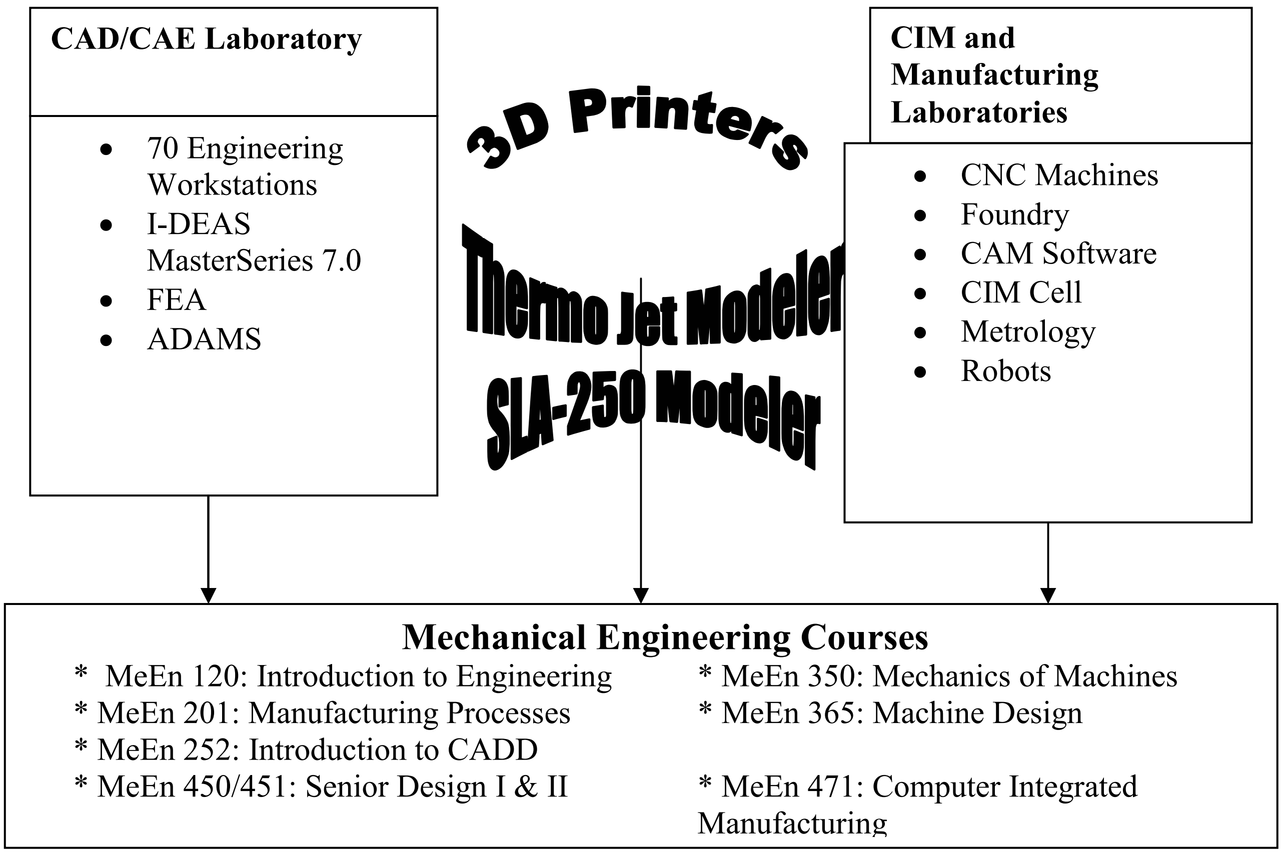

Figure 1: 3-D Printing Implementation Plan

A partnership agreement has been negotiated between 3D Systems Company and Southern University, to best utilize these machines for undergraduate education and to serve as demonstration and training site. The implementation plan for 3-D printing is schematically presented in Figure 1. There are books that address rapid prototyping (RP) technologies focusing mostly on stereo-lithography process[9-10]. A comparison of commercially available 3-D printers is presented in Table 1. Our choice of ThermoJet and SLA-250 was based on several considerations including initial equipment cost, operating and material cost, maintenance expenses, and past successful application in academic setting. Five universities located within 400 miles radius, from Baton Rouge area have recently implemented ThermoJet technology in the curriculum. The additional favorable consideration is the partnership agreement between Southern University and 3D-Systems Company.

Manufacturer Model	3-D Systems ThermoJet Solid Object Printer	Stratasys Genesys Xs	Z Corporation Z402
Technology	Multi-Jet modeler	Fused Deposition Modeling	Ink-Jet
Material Type	Thermoplastic	Polyester	Starch/plaster powder
List Price	$49,995	$45,000	$59,000
Max. Part Size	10in.x 7.5in.x 8in.	12in.x 8in.x 8in.	10in.x8in.x8in.
Material Cost	$99/lb in 5 lb bottles	$180/lb in 50 cartridges	Zp11=$35 per vert. in. Zp100~$50-$75
Min. Layer Thickness	0.04 mm	0.36 mm	0.01mm
Accuracy	Variable accuracy depending On needs	+/-0.36 mm	Suitable for small delicate jewelry parts
Speed	Fast file preparation STL viewer Fast optimized build time	Slow file preparation Fast build times	Plaster powder 2X slower than starch
Design Office Environment	Office friendly (CE, UL approved) Dimensions: 54in.x30in.x44in. Weight: 826 lb	Office friendly (CE approved) Dimensions: 36in.x32in.x29in. Weight 210lb	Not appropriate for Office use
Surface Finish	Smooth, highly detailed surface	Poor detail, coarse delaminated layers	Rough grainy surface
Resolution	X=0.0635mm, Y=0.0838mm Z=0.0406mm	0.0302mm	XY constrained by particle size Z: 0.133 mm (Max)

Table 1: Comparison of commercially available 3-D printers

The implementation of 3D-printing machines will enable us to achieve the following goals:

- Strengthen the engineering design curriculum by providing a medium of communicating design intricacies and relating CAD designs to 3D solid models that one can "toy with".
- Enhance the computer-aided design and computer-aided manufacturing (CAD/CAM) courses through increased use of printed 3D solid models.
- Strengthen the manufacturing processes course by introducing rapid prototyping tools for the manufacture of casting patterns, tooling, jigs, and fixtures.
- Provide undergraduate students with exposure to the state of the art technologies capable of integrating design-manufacturing experience.
- Provide area businesses with a demonstration and training site capable of quickly producing affordable 3D solid models of their concept designs. The concept validation

possible with the rapid prototyping will provide them a competitive edge and hence economic opportunities.

- Enhancement of the capstone design course projects.

IV. Outcomes Assessment

Evaluation of the progress and effectiveness of the enhancement of engineering design and manufacturing courses are essential factors to convince our faculty members and our stakeholders of soundness of the proposed approach. To this end, each related course must have an assessment process with documented results. Evidence must be given that the results are applied to the further development and improvement of the related courses.

Input, authentic performance, and longitudinal assessment methods and tools form the methodological basis of the assessment process. Development and selection of assessment tools for determining the success and effectiveness of the enhancement process are based on the following criteria. The assessment tools must: 1- be valid and reliable, 2- assess effectiveness at the individual course level, 3- reflect actual classroom activities and assignment, 4- take little faculty time to administrate, and 5- measure stated goals effectively and efficiently.

Based on those criteria, following tools to assess the outcomes are suggested: 1- student self- and peer evaluations, 2- design project proposals and final reports, 3- assignment based on industry sponsored projects, and 4- student basic competency evaluation. These tools will form the core assessment of the enhancement of engineering design and manufacturing courses. The Department's assessment coordinator is in charge of the overall curriculum assessment. At the end of every semester, data are collected and analyzed by the assessment coordinator to determine how many performance criteria are met. Finally, feedback is provided to each course instructor to facilitate continuous improvement of activities.

V. Conclusion and Discussion

Plan for the implementation of 3D printers and their incorporation in the design-manufacturing curriculum is described in this paper. The experiences of other engineering programs that have implemented similar technology will contribute towards enhancing engineering education. It is expected that the use of 3D rapid prototyping printers in the curriculum will positively impact the student learning, attention, and retention. We plan to undertake assessment of this aspect during the implementation of 3D printing technology. It will be very enlightening to compare our results with others with similar technology. Industrial partnership and training of industry for 3D printing is expected to be mutually beneficial. The industrial collaboration is expected to result in growing student interest and healthy curriculum.

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GHANASHYAM JOSHI
Ghanashyam Joshi is currently an Associate Professor of Mechanical Engineering at Southern University, Baton Rouge, Louisiana. He received a B. Tech. Degree in Mechanical Engineering from Indian Institute of Technology, Bombay, in 1986, M.S. in Mechanical Engineering from North Dakota State University, in 1990, and a Ph.D. in Mechanical Engineering from Michigan Technological University, in 1993. He served as an ASA/NSF/NIST Research Associate at NIST, Gaithersburg, MD during 1993-94. Dr. Joshi's research interests are primarily in the areas of manufacturing, automation, robotics, vibration-based condition monitoring, and reliability engineering. Dr. Joshi is a registered Professional Engineer in the state of Louisiana.

SAMUEL IBEKWE
Dr. Samuel Ibekwe is an Associate Professor of mechanical engineering. His interests are in Design, Manufacturing, and Engineering mechanics area. He has taught various design classes including 'Introduction to Freshman Design' and is currently the coordinator of Design courses for mechanical engineering department including the capstone design courses. He has been working assiduously to enhance the instructional delivery of design and manufacturing courses. A past recipient of the department's faculty of the year award, Dr. Ibekwe is a Louisiana State registered professional engineer who holds one design U.S. patent. He has a lot of funded research projects from Louisiana Board of Regents, NSF, DoD, LaSPACE, and private industries.

PATRICK F. MENSAH
Patrick Mensah is an Associate Professor of Mechanical Engineering at Southern University, Baton Rouge, Louisiana. He received a BS degree in Mechanical Engineering from the University of Wisconsin- Milwaukee (UWM), Wisconsin, in 1988, and also an MS degree in Mechanical Engineering from UWM in 1991. He joined the Southern University faculty in 1991 while pursuing his Ph.D. at Louisiana State University, Baton Rouge, Louisiana. He received his Ph.D. in Engineering Science with options in Mechanical and Chemical Engineering in 1998. His current research interests are in thermal fluid sciences, composite materials with emphasis on thermal characterization and thermo-mechanical analysis, automatic control of heating processes and finite element applications.

HABIB MOHAMADIAN
Habib Mohamadian is a Professor and Chairman of Mechanical Engineering at Southern University, Baton Rouge, Louisiana. He also serves as the College of Engineering Assessment Coordinator and is a member of SACS preparation team. Dr. Mohamadian is a registered Professional Mechanical Engineer and is involved in industry-sponsored senior projects. Dr. Mohamadian received a B.S. degree in Mechanical Engineering from the University of Texas at Austin in 1976 and a Ph.D. from the Department of Mechanical Engineering at Louisiana State University-Baton Rouge in 1982.