AC 2011-2227: EXPANDING A MANUFACTURING TECHNOLOGY CURRICULUM TO INCLUDE ADDITIVE MANUFACTURING

Chin-Zue Chen, Austin Peay State University

Dr. Chin-Zue Chen is a Professor of Engineering Technology Department at Austin Peay State University, Clarksville, Tennessee, where he has taught and in charge of robotics program since 1985. He initiated PLC, CAM, CIM, Sensors and Vision Systems courses in earlier years of his teaching, and involved in Additive Manufacturing in recent years. Prof. Chen is a Fellow of the Tennessee Academy of Science.

Adel Salama., Austin Peay State University

Prof. ADEL SALAMA, M.S., P.E. Adel Salama is a Professor and Chair of Engineering Technology Department at Austin Peay State University where he has taught since 1990. Prior to this he taught for seven years at different institutions and twenty years service in Air Force and petroleum industry. He is a registered Professional Engineer and Member of National Society of Professional Engineers and Member of IEEE since 1990. He and the department faculty had extensive curriculum revisions for the Engineering Technology Department which has led to TAC of ABET accreditation.

Expanding a Manufacturing Technology Curriculum to Include Additive Manufacturing

The conventional manufacturing technique of making a part is cutting, or subtracting, the material out of a block of material to form the shape of the part. This technique is called Subtractive Manufacturing (SM). During the product design process one typically needs to create a prototype for form, fit, and function evaluation. Applying the SM approach to make a prototype is usually time-consuming and expensive, thus there is a need to develop a faster and cheaper process to produce prototypes. As a response to this need, rapid prototyping (RP) was developed in the early 1970s. In the late 80s and early 90s, RP techniques started to bloom.[1]

With RP, an object designed in 3D CAD can be directly built by a machine into a physical product, layer by layer. To do this, the virtual object in 3D CAD is sectioned, from the bottom up, into 2D slices with space in between each slice equaling the thickness of the layer to be built by the machine. Then, in accordance to this section data, the machine builds the object, layer upon layer from the bottom up to form the 3D object. This new approach of adding material to produce a part is classified as additive manufacturing (AM). Within the most recent twenty years of continuous research, development, and application, the increasing power of computers, CAD software, and newly developed materials and equipments has made RP an extremely promising technology in AM [2]. RP can be used not only to produce prototypes or functional models, but also to produce parts for direct use; this direct-part production has grown to become the second most common application of AM technology [3]. This development in AM has a tremendous impact on product design and manufacturing, and this impact is predicted to become greater in the coming years [4].

Having realized the importance of stimulating research and promoting AM, the National Science Foundation and the Office of Naval Research sponsored the Roadmap for Additive Manufacturing (RAM) Workshop in March 2009 to develop a roadmap for research in additive manufacturing for the next 10-12 years [1]. ASTM International, partnering with SME, has developed standard terminology for AM Technology at the end of 2009, and is developing standard for this new technology in test methods, design, materials, processes, etc. [5,6] With this growing trend, there are demands for education institutes to provide students with opportunities to explore AM technologies. In response to the needs [1], some institutions modified existing courses to include AM contents [7,8], some created a new course to introduce AM technologies, [9,10] and some institutions even designed new curricula to properly prepare students who are pursuing careers that use these cutting-edge technologies [11].

The Engineering Technology Department at Austin Peay State University in Tennessee is TAC-ABET accredited in manufacturing and electrical curricula. Currently, the manufacturing curriculum encompasses manufacturing and manufacturing with robotics concentrations, and the electrical curriculum includes electronics and electrical with robotics concentrations. The majority of students in the department are nontraditional students, primarily from the military and local industries; therefore, the department offers evening classes. Although AM technology is currently not popularly known in local industries, it has been implemented in some companies in the nearby cities of Tennessee and Kentucky, and its impact will increase in this region. In order to expose the students to AM technology, the Engineering Technology Department acquired a 3D printer in 2009 to develop an introductory course. Before the course was offered, it was suggested to expand and add an Additive Manufacturing Option to the existing manufacturing curriculum in order to encourage and prepare students to pursue careers in this new and expanding area. It is hoped that the students will come to have a positive influence on increasing awareness and implementation of AM technology in the local industries where they are employed.

The manufacturing curriculum requires 125 semester hours, including 44 hours of Liberal Arts core, 45 hours of Engineering Technology core, and 36 hours of concentration courses. Within the concentration, there are 18 hours for the Manufacturing core and 18 hours, or 6 courses, for the concentration, including 2 elective courses. See Table 1. "Manufacturing Curriculum Check Sheet" for detail.

In preparation for the Additive Manufacturing Option, four new courses were designed, a pool for two elective courses was selected, and an AM lab set up is planned.

There are four courses designed to compose a major part of the Additive Manufacturing Option:

1. ENGT 3130 Additive Manufacturing Technology (3).
   Prerequisite: ENGT 2730 (Intro to Solid Modeling)
   This course will cover a brief history and development of Rapid Prototyping (RP) technology, compare Additive Manufacturing (AM) and Subtractive Manufacturing (SM), and introduce AM technologies and their base materials. There will be hands-on labs for students to design parts on CAD and produce them with 3D printers, and a fieldtrip to visit metal deposition technology centers.
2. ENGT 3190 3D Laser Scanning and Reverse Engineering (3).
   Prerequisite: ENGT 3130 (1st AM course)
   The course will introduce reverse engineering, operating principles of 3D scanning, and applications of 3D laser scanners. Students will apply knowledge of 3D scanners for reverse engineering and direct digital fabrication purposes.
3. ENGT 4130 Additive Manufacturing Applications (3).
   Prerequisite: ENGT 3190 (2nd AM course)
   This is a project based course. Each team will design a product that is difficult or impossible to fabricate using SM technology, and then utilize the AM technologies available in the lab to fabricate the product. Students will search current AM R & D and application information and make presentations to share in class.
4. ENGT 4190 Additive Manufacturing Capstone (3).
   Prerequisite: ENGT 4130 (3rd AM course) & ENGT 4850 (Computer-Integrated Mfg)
   This is a capstone project driven course. Using role play in a company organization setting, students will apply knowledge learned in other courses to go through market search, product design, and production, ending with a final product made with AM technology. Through the course students will learn or enhance teamwork, interpersonal, social, and leadership skills.

Table 1. Manufacturing Curriculum Check Sheet

Austin Peay State University

Engineering Technology Department

Curriculum Check Sheet

Manufacturing Concentration

Name				
Anticipated Grad Date				
Transferred from:				
Libral Arts Core	***Cr. APSU***	***Hrs Trans***	***Trans From***	***Req Cr.***
APSU 1000				*1*
Communications (9 Cr.)				
ENGL 1010 English Comp I				*3*
ENGL 1020 English Comp II				*3*
COMM 1010 Fund Pub Spkg				*3*
History (6 Cr.)				
HIST 2010 American History				*3*
HIST 2020 American History				*3*
Humanities (See Catalog 9 Cr)				
ENGL 2030 World Literature				*3*
				3
				3
Social Sc (See Catalog 6 Cr)				
				3
				3
Mathematics (3 Cr.)				
MATH 1530 Elem of Statistics				*3*
Natural Sciences (8 Cr.)				
PHYS 2010 College Physics				*5*
PHYS 2020 College Physics				*5*
Libral Arts Total Cr.				***44***

Regular Curriculum - 124 Cr. Hrs ***125***

Student Signature ***Date***

Advisor ***Date***

Department Chair ***Date***

Engineering Tech Core	***Cr. APSU***	***Hrs Trans***	***Trans From***	***Cr.***
ENGT 1000 Intr to Engt				***3***
ENGT 1020 Comp Aid Design				***3***
ENGT 2000 Manuf Processes				***3***
ENGT 2010 DC Circuits				***3***
ENGT 2020 Robotic Fund				***3***
ENGT 2030 AC Circuits				***3***
ENGT 2730 Intro to Solid Model				***3***
ENGT 3000 Material Science				***3***
ENGT 3010 Eng. Economics				***3***
ENGT 3020 Stat&Sten of Mat				***3***
ENGT 3030 Thermodynamics				***3***
ENGT 3040 Power Transfer				***3***
ENGT 3050 Problem Solving				***3***
MATH 1730 or ENGT 1200				***3***
MATH 1810 or ENGT 1400				***3***
Eng Tech Core Total				***45***
Concentration: Manufacturing Core	***Cr. APSU***	***Hrs Trans***	***Trans From***	***Cr.***
ENGT 3610 Prod Oper Mgmt				***3***
ENGT 3800 Comp Aid Manu				***3***
ENGT 3810 Plastic Manufact				***3***
ENGT 3850 Manu Proces II				***3***
ENGT 4800 Machine Design				***3***
ENGT 4850 Comp Intg Manu				***3***
Manufacturing				
ENGT 3830 Metal Manufact				***3***
ENGT 4720 Advanced CAD				***3***
ENGT 4810 Adv Manufact				***3***
ENGT 4991 Mfg Capstone Projt				***3***
ENGT				***3***
ENGT				***3***
Electives ENGT 3100, 3650, 3660, 3840, 3990,4150, 4710, 4870				
Additive Manufacturing				
ENGT 3130 Additive Manuf Tech				***3***
ENGT 3190 3D Scan & Rev Eng				***3***
ENGT 4130 Addit Manuf Applic				***3***
ENGT 4190 AM Capstone Projt				***3***
ENGT				***3***
ENGT				***3***
Electives ENGT 3100,3650,3810,3830,4150,4810				
Robotics Manufacturing				
ENGT 3100 Robotic Applica				***3***
ENGT 4120 Sensor & vision				***3***
ENGT 4150 Prog Logic Cont				***3***
ENGT 3260 Microprocessor				***3***
ENGT				***3***
ENGT				***3***
Electives ENGT 3130, 3250, 3650, 3830, 4810				
Concentration Total				***36***

Students elect two courses from the following to fulfill the electives for the Additive Manufacturing option:

ENGT 3100 Robotic Applications (3)
ENGT 3650 Statistical Quality Control (3)
ENGT 3810 Plastics Manufacturing (3)
ENGT 3830 Metals Manufacturing (3)
ENGT 4150 Programmable Logic Controls (3)
ENGT 4810 Advanced Manufacturing Processes (3)

More than ten different technologies are utilized in AM today, and the selection of equipment for the AM lab is based on the following criteria:

1. The machines in the lab shall represent different technologies.
2. The machines in the lab shall utilize different types of materials and forms.
3. The machines in the lab shall be able to produce durable products with good precision for other possible applications.
4. Machines that utilize metal materials are temporarily not considered, due to the facility and budget limitations.
5. A 3D laser scanner shall be considered for reverse engineering, 3D laser scanning technology, and rapid prototyping.

The selected equipments and their technologies, build techniques, materials used, and acquisition status are list below:

1. Objet Alaris 30 3D Printer (Figure 1)
   *Technology: Polyjet 3D printing (3DP) (Figure 2)
   *Build technique: one polyjet head deposits liquid proprietary acrylate photopolymer and other head deposits liquid support material (soluble), both hardened by UV light.
   *Acquisition: requested in January 2009 and acquired in August 2009.

2. Dimension Elite 3D Printer (Figure 3)
   *Technology: Fused Deposition Modeling (FDM) (Figure 4)
   *Build technique: a heated extrusion tip melts and extrudes ABSplus plastics; other tip extrudes soluble support material.
   *Acquisition: requested in September 2010 and the purchase order is being processed, as of March 2011.

3. Z Corp Z450 Color 3D Printer (Figure 5)
   *Technology: MIT's inkjet 3D printing (3DP) (Figure 6)
   *Build technique: the inkjet heads jet colored liquid binder onto composite powder or ceramic powder.
   *Acquisition: requested in October 2010 and the purchase order is being processed, as of March 2011.

4. NextEngine 3D Laser Scanner
   *Acquisition: requested January 2010 and currently waiting for delivery.

Figure 1 Objet Alaris 30 Printer

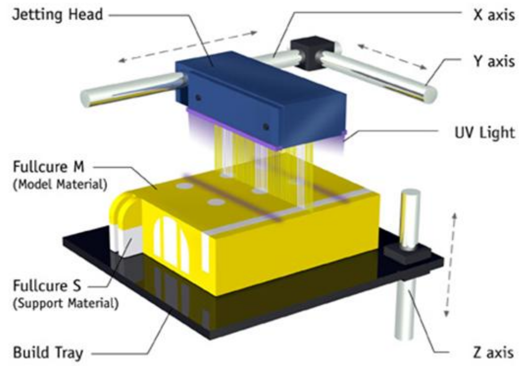

Figure 2   Polyjet Process

Figure 3 Dimension Elite Printer

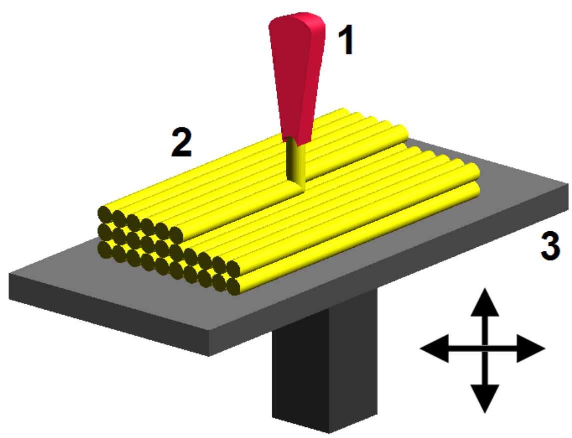

Figure 4 Fused Deposition Modeling (FDM)

Figure 5 Z450 Color Printer

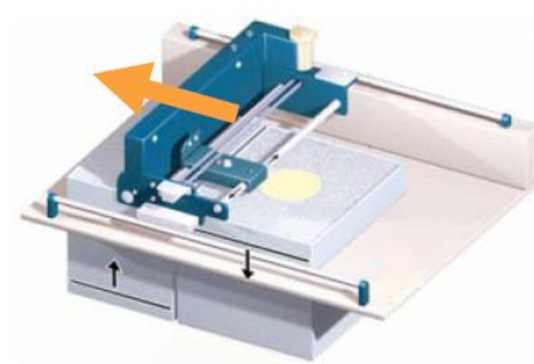

Figure 6 MIT's Three-Dimensional Printing (3DP)

The current room housing the Alaris30 printer has just enough space for one of the new machines; therefore, a larger lab space is required. With the support and negotiation efforts of the Executive Director of the School, a 30 ft x 16 ft room space was acquired in early January, 2011 as the new lab.

With the lab space issue solved, the implementation schedule of the proposed AM option is projected below:

2011 in the first half of the year –
* have AM Option approved,
* move into the new AM Lab,
* install the Elite FDM 3D printer,
in the second half of the year –
*install the Z450 Color 3D printer,
*offer ENGT 3130 AM Technology

2012 in the first half of the year –
*offer ENGT 3190 3D Laser Scanning & Reverse Engineering.
in the second half of the year –
*offer ENGT 4130 AM Applications.

2013 in the first half of the year –
*offer ENGT 4190 Capstone Project.

Before implementing the AM concentration, there still is an issue to be resolved, that of the current faculty course load. There are two faculty members who have been involved in AM technology for several years and are candidates to teach this concentration. The problem is, the two faculty members already have full teaching loads and are very often required to carry an overload; thus it is difficult to request them to take on an even heavier load. Three possible solutions are considered:
(1) open a faculty position, and search for a candidate with the necessary background to teach AM courses;
(2) hire adjunct faculty to teach the AM courses;
(3) ask existing adjunct faculty or hire new adjunct faculty to teach some of the two faculty members' courses so that the faculty are available to teach the AM courses.

The assessment of the Additive Manufacturing option will include course assessment, the university's Student Learning Outcomes evaluation, and a follow-up survey after the student becomes employed. The course assessment will be through class tests (mainly essay questions), presentations, lab performances, and reports. For the capstone, the assessment will be through project performances & reports, student's self & peer evaluations, instructor's observations, and a semester-end questionnaire. The Curriculum Matrix – relationship of courses to the university's Student Learning Outcomes – will be evaluated accordingly. During the first two years of employment, students and their employers will be surveyed for purposes of curriculum improvement.

In conclusion, the development of rapid prototyping and additive manufacturing technologies has created a new dimension in manufacturing and is greatly impacting today's manufacturing industries. In adapting to the new changes, education institutions are updating their courses contents, introducing new courses, or setting up new curricula to fulfill future demands. The Engineering Technology Department at Austin Peay State University in compliance with current needs, proposed adding an Additive Manufacturing option under its manufacturing curriculum to provide opportunities for students to explore to this new technology and adapt to new career opportunities. A sequence of four new courses has been designed and an AM Lab setup is ongoing. Although the Department will encounter faculty teaching load issue, this new Additive Manufacturing Option will be implemented to benefit students.

References

1 Bourell, D. L. (2009). "A Brief History of Additive Manufacturing and the 2009 Roadmap for Additive Manufacturing: Looking Back and Looking Ahead". RapidTech 2009: US-TURKEY Workshop on Rapid Technologies. http://iweb.tntech.edu/rrpl/rapidtech2009/bourell.pdf

2 Chua, C. k. and K. F. Leong (2000). *Rapid Prototyping: Principles and Applications in Manufacturing.* Singapore: World Scientific.

3 Wohlers, T. (2010). *Wohlers Report 2010 – Additive Manufacturing State of the Industry, Annual Worldwide Progress Report.* Fort Collins, CO: Wohlers Associates.

4 Wohlers, T. (2010). "Developments in Additive Manufacturing," *Manufacturing Engineering*, 1 (144).

5 ASTM Additive Manufacturing Committee Approve Terminology Standard http://www.astmnewsroom.org/default.aspx?pageid=1944 (accessed December, 2010)

6 Additive Manufacturing Gets a "Universal Language" http://www.sme.org/cgi-bin/get-press.pl?&&20100002&PR&&SME& (accessed December, 2010)

7 Johnson, W. M., C. W. Coates, P. Hager, and N. Stevens (2009). "Employing Rapid Prototyping in a First-Year Engineering Graphics Course," *in Proceedings of the ASEE Southeast Section Conference.*

8 De Leon, J. E. and G. Winek (2000). "Incorporating Rapid Prototyping into the Engineering Design Curriculum," *Engineering Design Graphics Journal*, 1 (64), pp. 18-23.

9 Bohn, J. H. (1997). "Integrating Rapid Prototyping into the Engineering Curriculum – A Case Study," *Rapid Prototyping Journal*, 1 (3), pp. 32-37.

10 Leake, J. M. (2004). "Development of an Advanced Course in Computer-Aided Design, Analysis and Prototyping," *in Proceedings of the ASEE Annual Conference.*

11 Saddleback College Rapid Digital Manufacturing Certificate Program. *www.saddleback.edu/atas/Rapid_Digital_Manufacturing/* (accessed December, 2010)