Interactions of an Additive Manufacturing Program with Society

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Abstract

Additive Manufacturing (AM) has shown considerable promise for the future but also proposes some challenges. Many AM barriers tend to be non-technical and instead are human-centric issues such as lack of education of practitioners in AM capabilities, cultural differences, vested interests, and potentially lack of imagination. It is highly desirable for all research and educational institutions to help address these issues. This paper summarizes the additive manufacturing research and education program at the Missouri University of Science and Technology (Missouri S&T) and its interactions with various constituents, including K-12 students, undergraduate and graduate students, distance students, and industry.

Introduction

Additive Manufacturing (AM) is a freeform manufacturing process that allows users to fabricate a real physical part directly from a CAD (Computer-Aided Design) model. The CAD model is sliced into many layers by any number of software packages that can also prepare the part for the specific layered manufacturing machine that will be used. The part is then built layer-by-layer without extraneous tools. This process allows one to quickly build geometrically complex parts. AM technologies can greatly reduce cycle time. However, there are many other benefits that are not fully used in industrial practice. One of the major reasons for this issue is educational awareness. In other words, most engineers are not designing parts and products with AM technologies in mind, which is due to the fact that AM technologies were not taught during their education.

To overcome these barriers, a program of education is recommended [Bourell09]: 1) University courses, education materials, and curricula are needed at both the undergraduate and graduate levels; 2) Similar needs exist at the technical college level, and 3) Training programs for industry practitioners, perhaps with certification by professional societies or organizations (e.g., SME, ASME). In addition to formal education programs, outreach to the non-technical population is also needed: 1) Programs for management or other non-technical business personnel on logistics, lean manufacturing, new business models, etc.; 2) Programs for educating the general population would enhance the interest in AM applications and generate some societal "pull" for these technologies. Outreach could take the form of museum exhibits, "product placement" in television shows and movies, topical segments on popular shows, or creative advertising and marketing campaigns for new products. This paper provides an overview of the interactions of the additive manufacturing program at Missouri S&T with the society.

AM Laboratories and Related Facilities at Missouri S&T

The AM laboratories and facilities at Missouri S&T include commercially available machines as well as very unique research facilities. We have used the existing campus prototyping resources and those available from industries to provide distributed prototyping experiences for companies, students, and other partners. The Additive Manufacturing Laboratories at Missouri S&T have the following major pieces of equipment:

Freeze-form Extrusion Fabrication

As shown in Figure 1, the Freeze-form Extrusion Fabrication (FEF) process with a triple extruder, was developed by Missouri S&T, for the fabrication of 3D ceramic or ceramics-based composite parts from single, multiple, or graded aqueous pastes. It is an additive manufacturing process that extrudes aqueous pastes of high solid loadings layer-by-layer in an environment below the water freezing temperature. As shown in Figure 2, we have successfully demonstrated building 3D parts from high and ultra-high temperature ceramics including aluminum oxide (Al_2O_3) and zirconium diboride (ZrB_2), as well as 13-93 bioactive glass, using the developed FEF system [Huang06, Huang07, Mason09, Huang09, Zhao10]. The ceramic parts obtained after binder burnout and sintering have been shown to have near full density and possess very good mechanical properties. We have also investigated using the FEF process to fabricate parts with functionally graded materials (FGMs) [Leu12]. For this purpose we have designed and developed a triple-extruder FEF machine and used this machine to fabricate parts from multiple aqueous pastes of changing proportions continuously as programmed, resulting in a part graded between two different materials (which could be both ceramics or could be one ceramic and one metal). We have experimentally verified the feasibility of using the FEF process to fabricate FGM parts and have performed mechanical testing and microstructure evaluation on the produced test specimens after the post processes of freeze drying, debinding, and sintering.

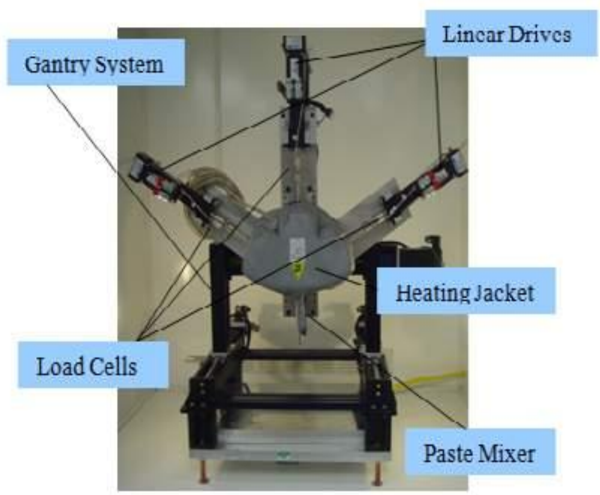


Figure 1. The Triple-Extruder FEF machine at Missouri S&T

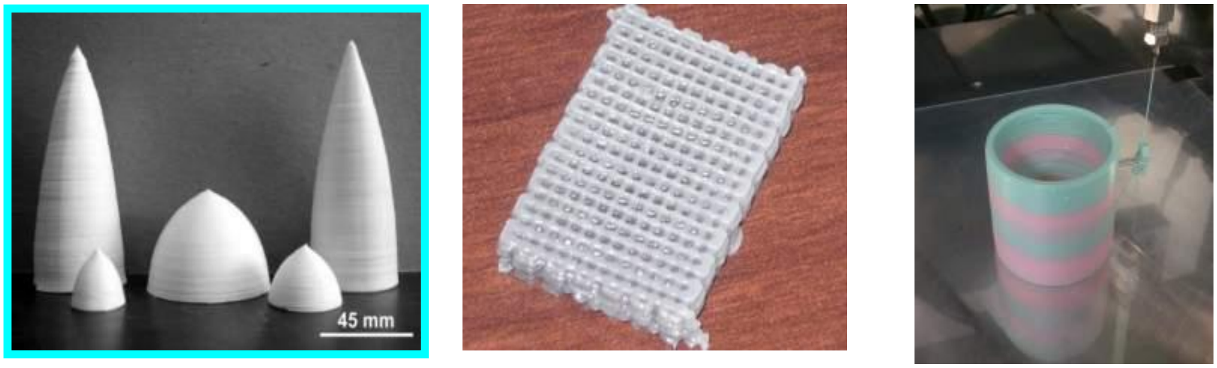


Figure 2. Sample parts fabricated by the FEF process

<u>Selective Laser Sintering</u>

We have studied using the Selective Laser Sintering (SLS) process (DTM2000) as shown in Figure 3 to fabricate parts from various materials for aerospace, biomedical, and energy applications [Kolan11, Bourell11, Guo12, Leu12]. Figure 4 shows three sample fuel cell bipolar plates with different flow patterns fabricated by the SLS process. This includes fabricating Zirconium Diboride (ZrB_2) parts used in hypersonic vehicles and high-performance propulsion systems, graphite composite bipolar plates for fuel cells, and 13-93 bioglass scaffolds used as bone implants. Experiments were conducted to determine the SLS process parameters (laser power, scan speed, scan spacing, layer thickness, etc.) that could successfully build a variety of parts with various geometrical features and good mechanical, thermal and biological properties. The research also included identifying the binder material required for the SLS process and the temperature and material requirements for the post-processing steps including binder burnout, sintering, carbonization, infiltration, etc. The research also included characterization of the properties (flexure strength, electrical conductivity, relative density, porosity, etc.) of the obtained final parts.

Figure 3. The Selective Laser Sintering machine (DTM 2000)

Figure 4. Example bipolar plates fabricated by the SLS process

Fused Deposition Modeling

Missouri S&T has a Fortus 400 machine (shown in Figure 5), an FDM300 machine and a Dimension 3D printer, all from Stratasys, for both research and education. We use the Fused Deposition Modeling (FDM) process to investigate manufacturing of complex parts from thermoplastics. Some sample parts fabricated using the Fortus machine are shown in Figure 6. Thermoplastics based complex mold geometries will be fabricated using the FDM process, and the fabricated molds will be assessed for coefficient of thermal expansion, mechanical properties and thermal conductivity. Also, surface treatments for the mold, backing material, and tool cycling will be assessed. The molds will be used to fabricate thermoset based composite parts using the Vacuum-Assisted Resin Transfer Molding (VARTM) process.

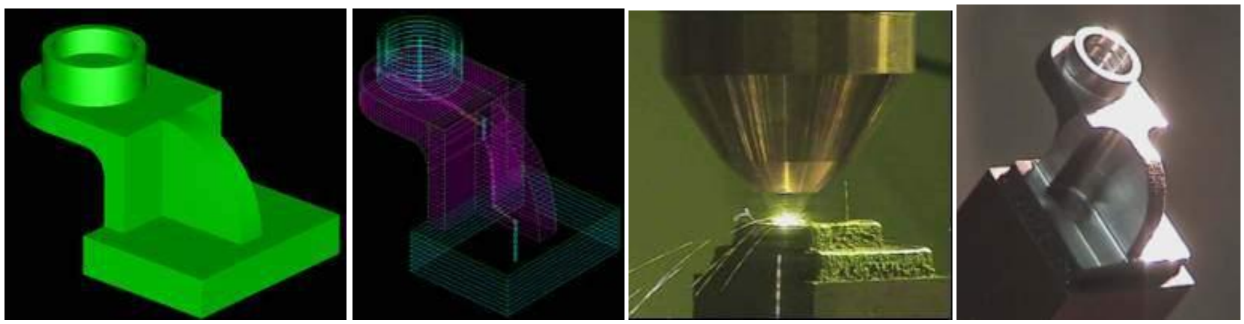
Figure 5. Fortus 400 machine from Stratasys

Figure 6. Sample parts fabricated using the Fortus machine (http://www.stratasys.com/)

Hybrid Manufacturing Process

As shown in Figures 7 and 8, the hybrid deposition (laser metal deposition) and removal (machining) manufacturing process at Missouri S&T has the ability to repair parts to extend service life and to build complex parts [Liou07, Nagel12]. Traditional welding repair has many limitations including excessive thermal deformation, poor metallurgical and mechanical properties due to the inconsistency of the microstructure, and large intolerance for the geometry change of the parts. In order to make full use of the automated hybrid process, research will be conducted on the repair of parts with high temperature materials. Since part microstructure and bonding of two materials in laser metal deposition processes is closely related to the melt pool temperature during fabrication, students will investigate the critical parameters and how to use these parameters to maintain a prescribed process temperature and temperature gradient such that the materials bond during processing and the part has the desired microstructure properties. Students will also research the planning methods for hybrid manufacturing to repair a part. As the hybrid process introduces complexity in terms of automation and planning, the research issues include determining optimal use of material deposition versus material removal to maximize operation productivity, and optimal schedules for automated probing to ensure part quality. Students will also create strategies for determining the quality of the repaired parts. They will build parts using variable laser power and constant laser power with different process plans and compare the resulting quality of the parts. A hybrid manufacturing process version 2.0 is also being developed to use a 6-axis robot and a 5-axis CNC machining center to process precision large metal parts.

Figure 7. Hybrid manufacturing process by LAMP (Laser Aided Manufacturing Process) Lab at Missouri S&T



(a) (b) (c) (d)

Figure 8. MAPS-driven hybrid manufacturing of an H13 tool steel bearing seat: (a) CAD model; (b) Automated generated tool path for deposition and machining; (c) Laser deposition; (d) After machining

AM Related Curricula at Missouri S&T

We have integrated the additive manufacturing related courses into a product realization curriculum to reinforce the critical competencies of students. This curriculum provides students with the experience of integrating skills toward rapid product realization. This curriculum also provides students with the experience of integrating the technical knowledge they have learned from other courses. The course sequence includes a design and basic CAD modeling course (ME 161), product modeling course (ME 363), a rapid prototyping course (ME 308), an integrated product development course (ME 358), and two advanced level classes (ME 459 and ME 463). These courses are summarized below.

ME 161: Introduction to Design provides students the opportunity to begin to apply learned knowledge to actual engineering systems—their first real chance to step into the role of an engineer. Through a hands-on approach, this lab course exposes students to basic design processes and methods as well as the integration of such knowledge into the production process. ME 161 requires students to devise and build a product to meet specifications set by the professor. In designing their projects, students also learn to use NX/Unigraphics, a computer-aided solid modeling package. This design and manufacturing challenge immerses the students in the entire engineering process. They develop a firm grasp of important engineering fundamentals even though they have limited exposure to engineering science.

ME 308: Rapid Product Design and Optimization: The aim of this course is to discuss the engineering procedure and the practice of applying rapid prototyping technologies to quickly deliver new products with lower cost and higher quality. Students not only learn about rapid prototyping technologies, but also gain a good understanding of using physical prototyping for product design and development with modern technologies and tools. The basics of the rapid prototyping procedure are introduced, including: 1) Constructing a CAD model, 2) Converting a CAD model into an STL format, 3) Checking and fixing the STL file, 4) Slicing the STL file to form layers, 5) Producing physical RP models, 6) Removing support structures, and 7) Post-processing RP parts. Various RP processes, such as liquid based processes (SLA, SGC (Solid Ground Curing) [SGC08, Liou07], Rapid Freeze Prototyping [Leu03, Liu06], etc.), solid based processes (FDM [Liou07], LOM (Laminated Object Manufacturing) [LOM08], UC (ultrasonic consolidation) [UC08], etc.), and powder based processes (SLS, LENS [LENS08], LAMP [Liou06, Liou07]) are also introduced. The application of rapid prototyping and other technologies to product realization is also introduced. Students have access to various RP processes, such as FDM, SLS, RFP, and LAMP, for part fabrication or for research. At the end of this course, a concept prototype of a sponsored project is implemented. The sponsors include industry, university research labs, and some private individuals/parties.

A project-based course, "ME 358: Integrated Product Development," is also offered in the curriculum. The focus of this course is to develop an engineering prototype. The semester projects are the focus of this course, and could be a continuation of the sponsored project from the previous rapid prototyping course. This course enables the students to learn the following subjects: 1) acquisition of customer's requirements, 2) problem formulation, 3) prototype cost estimation, 4) prototype conceptual design, 5) product/prototype representations, 6) product concept prototyping, 7) make or buy decision, 8) manufacturing process capabilities, 9) prototyping process identification, 10) assembly, and 11) prototype assessment.

The ME 363 course "Principles and Practice of Computer Aided Design" is an elective, internet-accessible course at the beginning graduate level. It discusses the fundamentals of computer-aided design with emphasis on mathematical representations of curves and surfaces, modeling of solids, as well as CAD/CAM data exchange and computer graphics. This course includes an introduction to digital design and manufacturing, which introduces the concept of CAD/CAM, from the creation of a Computer-Aided Design (CAD) model to the Computer-Aided Manufacturing (CAM) of a physical part. The CAM processes include primarily Numerical Control (NC) machining and additive manufacturing. Included in the introduction of additive manufacturing are the representation of a CAD model in triangular surface meshes (the STL format), the slicing of the triangular meshes into contours for each layer, and the generation of tool paths from the contours. Also introduced are several popular additive manufacturing processes including Laser Stereolithography (SLA), Fused Deposition Modeling (FDM), Selective Laser Sintering (SLS), Selective Laser Melting (SLM), 3D Printing (3DP), Laminated Object Manufacturing (LOM), as well as commercial machines that can be used to make 3D parts using these processes. Applications of these various processes are provided in the categories of design, tooling, and manufacturing, with practical examples in aerospace, automobile, biomedical and other applications.

The ME 459 course discusses advanced CAD/CAM and database integration. It starts with the basic principles of building blocks of manufacturing automation, manufacturing process automation, database and data structure of CAD/CAM, to CAD/CAM integration. The theme includes the review of critical hardware and software used in manufacturing automation; how CAD/CAM are integrated; and how CAD/CAM technologies can be applied in recent areas such as rapid manufacturing and micro/nano environment. Additive manufacturing processes are used as examples for CAD/CAM integration.

The ME 463 course "Advanced Digital Design and Manufacturing" is an elective course at the advanced graduate level. It has in-depth coverage on freeform modeling, reverse engineering, NC path generation, and immersive digital design. The topic on NC tool path generation covers both additive and subtractive manufacturing. For additive manufacturing, details are given on the algorithms used for the tool path generation, which consists of creating an STL file for the CAD model of a 3D object, slicing the triangular meshes in the STL file into contours for each layer, and generating the tool path for each layer. In the term project, the students are asked to create a software program that can generate the NC tool path for additive manufacturing, given the STL file of the CAD model of any 3D solid object. The software program is desired to be flexible enough to allow for the user to specify the layer thickness and the tool path spacing. Also, the software program should be able to generate both contouring and rastering paths; i.e., the program should be able to generate at least one contour path for each perimeter and fill the interior with raster paths. Bonus points are given for generation of tool paths for building support sections and for building parts with functionally gradient materials.

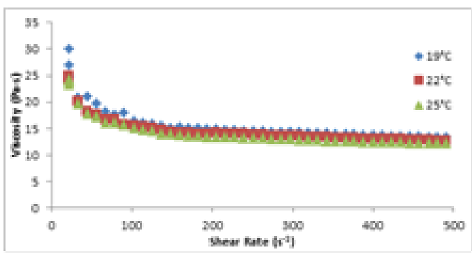
Research Experiences for Undergraduates

Missouri S&T has a Research Experience for Undergraduates site in Additive Manufacturing (AM REU Site), which is sponsored by the National Science Foundation. The program goals are to 1) introduce undergraduate students to all aspects of additive manufacturing, 2) provide students with individual challenging research projects in additive manufacturing that include analytical, computer aided design and analysis, and hands–on components in state–of–the–art research laboratories, 3) integrate individual research projects into an interdisciplinary, team–based environment where research results will be used to fabricate 3D components, 4) attract talented undergraduate students, particularly underrepresented students, to conduct research in additive manufacturing and motivate them to pursue graduate studies, and 5) provide extracurricular activities to expose the students to other exciting areas of research and cutting–edge technologies.

The first summer program was offered in 2011. An eleventh undergraduate student working on a research project in additive manufacturing that was funded by Missouri S&T was also included in the group. Five students worked on individual projects and six students worked in three groups of two. Two students worked on paste preparation and characterization for the FEF process. They developed paste preparation procedures for an alumina paste and a 50 vol% alumina 50 vol% zirconium oxide paste, and studied the properties of tungsten and zirconium carbide. These studies included sintering characteristics, microstructural analysis with scanning electron microscope (SEM) imaging, milling studies, particle size measurements, surface area analysis, dispersant testing for tungsten and zirconium carbide powders in water, and strength testing on test bars along with graded parts of equivalent material.

Another student utilized the finite element software package ANSYS to conduct numerical studies to determine the temperature profile of a part in a laser metal deposition process as the laser passes over the deposit and adds new layers. Techniques for adding material to the numerical simulation while the simulation was in process were investigated. Another student conducted accelerated sulfuric acid corrosion tests to analyze the variation in corrosion rates of 316L Laser Metal Deposited (LMD) Stainless Steel, 316L Metal Injection Molded (MIM) Stainless Steel, and 316 Wrought Stainless Steel. Another student compared the material properties of laser deposited Ti-6Al-4V with rolled Ti-6Al-4V samples. Particular emphasis was placed on yield strength, hardness, and fatigue properties. Additionally, titanium micro-milling parameters were examined to create small test samples so that local properties could be investigated. Two other students undertook a project to investigate the capabilities of a Fab@Home machine, which is a hobbyist machine that can be used for educational activities, to create complex parts and parts that contain two materials, such as silicon caulk, silicon gel, etc.

A group of two students developed techniques to manufacture Membrane Electrode Assemblies (MEAs) at a low cost in order to maximize the viability of producing fuel cells for this application. More specifically, electrospray was utilized as a method to deposit catalyst material in an additive fashion. They investigated dispersants that are needed in the process and nozzle design for good deposition. The last student mixed 13-93 bioactive glass, with mean particle sizes ranging from 44µm to 10µm, with stearic acid binder and used the mixture to fabricate bone scaffolds via indirect Selective Laser Sintering (SLS). Using CAD software, four scaffold designs with differing fractions of apparent porosity (72.95%, 65.21%, 58.77%, 52.33%) were made. After a post processing procedure, final densities and apparent porosity (60.52%, 51.15%, 44.56%, 27.92%) were found using Archimedes' Principle. Sample compressive strengths were determined and the influences of architecture and open volume were discussed. Some of the results are shown in Figure 9.



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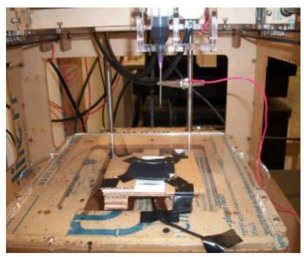

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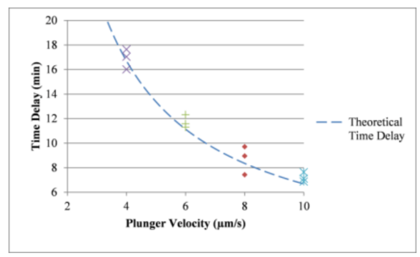
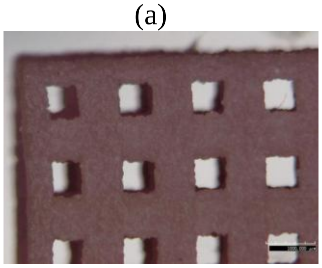


(c)



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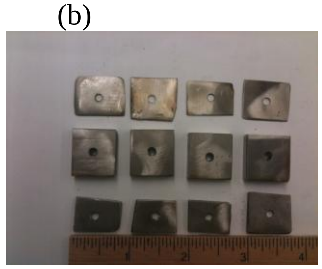

(e)

Figure 9. An example result of the summer 2011 AM REU Site program: (a) paste viscosity measurements, (b) electro-spray deposition machine, (c) analytical and experimental extrusion delay times, (d) SLS bone scaffolds, and (e) plates for corrosion testing

As an effort to help students improve their technical communication skills, a workshop on technical writing was offered during the 2011 summer program. The project team visited various companies and took tours of their facilities. These companies include Boeing, Anheuser Busch, Steelville Manufacturing, Mo Sci., and Brewer Science. The undergraduate students also went on a variety of social outings such as hiking, caving, and to an amusement park.

The AM REU Site program was rigorously evaluated. The assessment of the the effectiveness of the mentorship and found that students found the mentorship to be satisfactory (6.0/7), believing their mentors provided challenge (5.2/7), friendship (5.8/7), acceptance (5.2/7) and role model (5.1/7). Pre-post experimental studies were conducted to evaluate the program outcome. Pre-post questionnaire on students' interest in science and knowledge gained were measured. Results suggest that students who participated in the REU project were highly interested in science (5.6/7) and their knowledge on additive manufacturing improved substantially after the workshop (increased from 2.6/7 to 6.1/7). The effectiveness of the program was also assessed and the results indicated that students found the program to be informative (6/7), motivating (5.78/7) and applicable to real-world problems (6.11/7). To triangulate the results, a 10-item scale was adopted to assess the overall effectiveness of the program on students' abilities and knowledge, and the results indicated that the program was successful with an overall rating of 5.6/7. Students' perception of their writing skills were measured before and after the technical communication workshop and the results suggested that the technical communication workshop helped students improve their perceived technical communication skills.

Distance Education

In addition to the on-campus students, the Manufacturing Engineering program also offers a distance education option for working professionals. As many engineers while working in the manufacturing industry have found themselves with a lack of adequate knowledge in the manufacturing area, there is a great need to offer the distance program for these students. We have developed a "CAD/CAM & Rapid Product Realization" graduate certificate program that is accessible through the Internet. Students take one course from the following four core areas in the Manufacturing Engineering program: Course I: ME 363-Computer Applications in Mechanical Engineering Design; Course II: ME 308-Rapid Product Design and Optimization; Course III: ME 459-Advanced Topics in Design and Manufacturing; and Course IV: Select one from the following courses: ME 463-Advanced Digital Design and Manufacturing; ME-360 Probabilistic Engineering Design; ME 356-Design for Manufacture.

Many people working in industry are able to benefit from this program by participating through distance education and flexible scheduling. Students may attend class real-time via the Internet from home or place of employment. In most cases, there is a two way audio connection with the class to permit live interaction with other students and the instructor. All classes are archived on the internet to provide access to recorded lectures if they are unable to attend or need to review the material at a later date.

K-12 and Community College Interactions

In addition to the undergraduate program, we also interact with the society through teachers and students in K-12 schools and community colleges. For example, through an NSF RET program we have hosted visits of local elementary school students and teachers (1st, 2nd, 3rd, and 4th graders). Students were broken into small groups and toured the various labs at Missouri S&T. They were excited and curious to see the various AM machines and the robots. As shown in Figure 10, they were able to see an object scanned and a prototype being produced. Students received a sample to take with them.

Figure 10. Grade school student making a prototype after scanning an object on the lab computer

Figure 11. Unigraphics Activities

Several rapid prototyping sessions were held in the NSF sponsored "Discover Manufacturing Workshops," which introduced new technologies and concepts to the workshop attendees. This workshop was a collaborative effort between the Missouri University of Science and Technology and the St. Louis Community College at Florissant Valley. Its purpose was to expose high school students and teachers to manufacturing technologies in the hope of directing and impacting their career choices. The workshop was a one-week long program covering most of the areas in manufacturing. The schedule for the workshop is shown in Table 1. The week started with an introduction to solid modeling. NX/Unigraphics was used as the CAD tool (Figure 11) to give the participants hands-on experience in solid modeling. The next day we introduced rapid prototyping which was a new concept to most of them. They had hands-on experience on two machines, namely an FDM machine and the Thermaljet. Later in the week they were exposed to CNC machining, lean manufacturing and quality control.

Table 1 – Workshop Schedule

Mon.	Activities
9 am	Introductions and orientation
10 am	Manufacturing overview
10:40	Solid Modeling
11.30	Lunch Break
12:15	Solid Modeling
2:15	Solid Modeling
3:45	Wrap up day
4pm	Dismiss

Tue.	Activities
9 am	Introductions
9:15	Rapid Prototyping Introduction
10:15	Rapid Prototyping Lab
11.30	Lunch Break
12:15	Rapid Prototyping Applications
2:15	Rapid Prototyping Post processing
3:45	Wrap up day
4pm	Dismiss

Wed.	Activities
9 am	Introductions
9:15	CNC Machine Trainers
11.30	Lunch Break
12:15	Manufacturing Industry Tour
3:45	Wrap up day
4pm	Dismiss

Thur.	Activities
9 am	Introductions
9:15	Lean Manufacturing
10:30	Lean Manufacturing
11.30	Lunch Break
12:15	Lean Manufacturing
2:15	Lean Manufacturing
3:45	Wrap up day
4pm	Dismiss

Fri.	Activities
9 am	Introductions
9:15	Quality Control
10:30	Quality Control
11.30	Lunch Break
12:15	Plastic Processes
2:30	Guest Speaker
3:45	Wrap up day
4pm	Dismiss

The rapid prototyping activities included first a brief lecture on rapid prototyping. Then, the capabilities of several modern rapid prototyping processes were discussed. Workshop participants were given the opportunity to model and build their own pencil holders (Figures 12 and 13) using a Stratasys Dimension FDM machine.

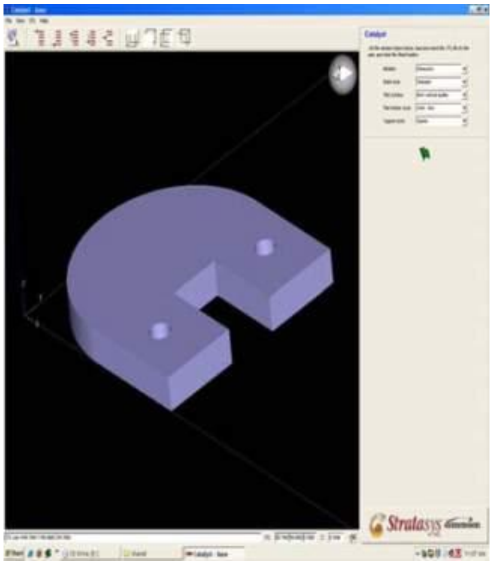

Figure 12. Pen Holder Base

Figure 13. Completed Pen Holder

At the end of the workshop, the workshop participants were given an opportunity to relate their experience at the workshop through a feedback form. Tables 2 - 4 summarize the feedback obtained from students and teachers. The feedback we received from the workshop attendees was very encouraging; teachers were able to relate mathematics and computer application with design, drafting and finally making the prototypes. They were in a better position to guide students concerning career opportunities in manufacturing. Based on the feedback, the workshop was very helpful in assisting the students with selecting a career. Tables 3 and 4 surveyed the participants which topics were of the most interest to them. Both teachers, in Table 3, and students, in Table 4, found rapid prototyping and industrial design to be engaging topics.

Table 2 – Some Results from Feedback Questionnaire

<table>
<tr><th>Students</th><th>Teachers</th></tr>
<tr><td colspan="2">Why did you attend the workshop?</td></tr>
<tr><td>
➢ To learn more about my future major.
➢ To advance my knowledge in the manufacturing process.
➢ I was uncertain about my future profession so this workshop could give insight about this field.
➢ To get a better look of how something were made by technology.
➢ To open up my options of manufacturing since it involved my favorite subject.
➢ Because my math teacher thought it would be good for me.
</td><td>
➢ Keep current on developments.
➢ To learn what I need to do in order to integrate math with real world.
➢ To learn about manufacturing, to inform students about this career field.
➢ To try to make connections between what I teach and the manufacturing process.
➢ To find out what careers and technologies are available for students.
➢ Better understanding of CNC and manufacturing to relate to students.
</td></tr>
<tr><td colspan="2">After attending this workshop, do you see any connections between this topic with a course you are taking/teaching?</td></tr>
<tr><td>
➢ Yes, most options like the fillet option where very similar to what we did in AutoCAD.
➢ Yes because I am going into aviation.
➢ Yes with the architectural drafting I have taken.
➢ Yes, I do and I plan to major in this subject.
➢ There is a connection between this course and algebra II.
</td><td>
➢ Yes, as students develop own products, can receive better understanding of the design, production and manufacturing.
➢ I'm beginning to see connections, generally with the presentations and the ability to communicate effectively.
➢ Definitely, as a math teacher I see mathematical and geometric connections in designing, drafting and finally producing the prototype.
➢ Yes, I use a variety of technology in class.
</td></tr>
</table>

Table 3 – Teachers: What Sub-Topic(s) are most interesting to you?

Teacher Comment	Notes
The FDM fused deposition modeling.	
The new research	At the end of the day, workshop attendees were introduced to research at the Laser Aided Manufacturing Process laboratory at UMR.
Hands on activity with the LAMP.	
The FDM process in general to learn the use of different polymers can result in working parts.	
Modeling in the computer using Unigraphics.	
The FDM machine's ability to mold prototypes with moving parts.	
Enjoyed participating in the production process from modelling to drafting the rapid prototype processing and seeing the machines work.	
Prototyping is the way of the future.	
The guest speaker today was excellent and pointed this workshop in the direction of understanding how this technology works.	A guest speaker from an industrial design firm introduced the workshop attendees to industrial design.
The material used in the prototyping, 3D modelling with Unigraphics, industrial design.	

Table 4 – Feedback from Students: What Sub-Topic(s) are most interesting to you?

Student Comment	Notes
Manufacturing.	
How prototypes are made and what can be made out of a prototype.	
Titan/CAD/CAM.	
The industrial engineer speech.	A guest speaker from an industrial design firm introduced the workshop attendees to industrial design.
Industrial design.	
That engineering is involved with manufacturing.	
I learned what prototyping is, and the different fields of engineering.	
Prototyping is just a play model of what your idea is.	
Using Solid Works.	
The different types of laser tech.	
About the cost and time of making the prototypes.	
The processes you go through to get the final product.	

Interaction with industry

Our interaction with industry has been primarily through the Center for Aerospace Manufacturing Technologies (CAMT). This Center was created in 2004 at the Missouri University of Science with major funding from the Air Force Research Laboratory. CAMT established an Industrial Consortium in 2007 in order to better disseminate information and transition technology for the aerospace supply chain in the United States. The Industrial Consortium is comprised of companies that pay annual fees in three categories: Gold Member - \$200K/yr, Full Member - \$50K/yr, and Associate Member - \$15K/yr. The Consortium currently has eight active members including one (1) Gold Member: Boeing, six (6) Full Members: Rolls Royce, Spirit AeroSystems, GKN Aerospace, Bell Helicopters, Siemens, KMT Waterjet, and one (1) Associate Member: Steelville Manufacturing. Past members included General Dynamics, Rockwell Collins, Titanova, Third Wave Systems, Product Innovation and Engineering, and Spartan Light Metal Products.

The research activities funded by the CAMT Industrial Consortium focus on fabrication and assembly technologies in the following areas: additive manufacturing, laser based materials processing, machine tools, waterjet cutting, composites fabrication and evaluation, friction stir joining, and assembly modeling and simulation. The current and recent past research projects in additive manufacturing funded by this Consortium include:

- Multi-Axis Planning System for Direct Fabrication and Repair of Metals
- Die Repair Using LAMP Hybrid Process
- Modeling of Novel Laser Cladding of High Temperature Alloys
- Surface Finishing of Additive Metal Processes
- A Multi-Axis Repair System (MARS)
- Prediction and Validation of Material Behavior Fabricated from Additive Metal Processes
- Laser Deposition for Metal Defect Rework
- Freeze-form Extrusion Fabrication of Composite Structures Using Ultra High Temperature Ceramics and Refractory Metals

Conclusions

AM technologies are emerging as key enabling practices for modern design and product development, and are revolutionizing the manufacturing process. Developing basics for this technology will take it out of isolation and propriety into the broader industrial and technological communities. The interactions of the additive manufacturing program at the Missouri University of Science and Technology with the society, including K-12 students, undergraduate and graduate students, distance students, and industry, are summarized in this paper. Students were exposed to both research and educational facilities through various AM focused projects and related curriculum. Distance students also have access to the program through the internet, thus they do not need to be physically on campus. The interactions with K-12 students and teachers were both fun and educational. The rapid prototyping session in the Discover Manufacturing Workshops was successful in introducing new technologies and concepts to the workshop participants. Also, the workshop faculty learned a great deal about dealing with students from varied backgrounds. While lectures are necessary for laying groundwork for more interesting activities, most of the feedback received during workshop asked for more time with hands-on activities. We hope that our additive manufacturing program will stimulate the future generation of engineers and technicians to work in the AM area.

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