Manufacturing Technology in Middle School Classrooms: A Collaborative Approach

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Abstract **- Today's global economy is based on emerging technologies that are rapidly challenging the knowledge base of its workers. The United States is challenged to develop a new workforce to compete in a global job market where the demand for science and engineering professionals continues to grow. To educate such a workforce, an effort must be made to close the gap between modern technology usage and its understanding. One important way to address this knowledge gap is by educating our youth about issues in technology and engineering, with a focus on manufacturing. This paper describes a successful outreach project focused on exposing middle school students to modern manufacturing tools and equipment. The middle school technology curriculum, assisted in part by the described university collaboration, includes educational modules in areas including computer-aided drafting, solid modeling, computer-aided manufacturing software tools, and computer-numerically controlled machining. Emphasis has been placed on providing educational tools to motivate, inspire, and potentially spark a future interest in manufacturing and engineering career paths. This paper explores the value of this collaborative venture as a model that university faculty members might use to develop or enhance opportunities for middle school students to experience hands-on technology education.**

Index Terms - K-12 Outreach, Middle School, Learning Factory, Manufacturing Education

INTRODUCTION

In today's modern technology-driven society, it is becoming increasingly difficult to ensure that the available workforce is properly trained and educated. Computers and computer-controlled equipment are now fully integrated into almost all aspects of the product development process and related tasks. As a result, many jobs now require some level of technical competence, and our educational systems are pressured to respond. In addition, the United States has been facing a problem of declining numbers of students expressing an interest, or majoring, in engineering [1]. Research conducted by the American College Testing (ACT) organization suggests that, at the very time our nation most needs promising students to enter majors and careers in science, technology, engineering, and mathematics (STEM), students' interest in these fields is on the decline. Over the past ten years, the percentage of ACT-tested students who stated an interest in majoring in engineering has dropped steadily from 7.6 percent to 4.9 percent [2]. In order to positively impact the future supply of engineers and scientists, our educational systems are charged with inducing technological literacy and related interest in young people. Many programs have been initiated in an effort to address these problems, with the vast majority being extracurricular in nature. This paper summarizes a collaborative project that utilizes the benefits of teaming college faculty with K-12 teachers as a means to better address these issues.

The authors recognize contemporary youth in their early teens to represent a meaningful target group for educational activities based on technology. First, these are formative years in terms of science and mathematics education, and often represent the times when bright, capable students, especially female, lose interest in these subjects. In addition, at this age students are often computer-literate and are beginning to develop into enthusiastic consumers of manufactured products. Their awareness of technologically advanced products may serve as a motivator in learning about the underlying concepts and processes involved in designing and manufacturing such items. Lastly, it is believed that most students map out their career paths by the time they enter their final year in high school [3]. With these things in mind, the overarching goal of the described activities is to enhance the STEM curriculum offered to middle school students in order to impress upon them the creativity and societal impact of engineering, and motivate them to learn science, technology, and mathematics and to consider related career paths. The implementation utilizes a model based on the idea that K-12 STEM curricula will benefit from collaboration and lasting relationships with university-level engineering communities. It considers the technology curriculum of a middle school in central Pennsylvania, the manufacturing-related educational enhancements of a neighboring university, and the curricular impact of the collaboration between the two.

This effort has received the financial support of the National Science Foundation (NSF) through the Course, Curriculum, and Laboratory Improvement (CCLI) program [4]. The primary focus of this CCLI project is the improvement of the manufacturing facilities and education available at the university level. This is accomplished through an adaptation of the Learning Factory (LF) model, emphasizing learning enhancements through practical hands-on experiences. The LF concept recognizes the need for

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both intellectual and physical activities to anchor the knowledge and practice of engineering in the minds of students [5]. Project funding has allowed for the purchase of new manufacturing equipment needed to improve hands-on learning opportunities in the areas of materials processing, manufacturing, and strength of materials. The resulting facility, as seen in Figure 1, has enabled the introduction of meaningful design and fabrication projects, materials processing experiments, and educational demonstrations. The described middle school activities represent the K-12 outreach portion of this CCLI project, and have been motivated by the purchase of new manufacturing equipment for the LF facility and the ability to donate the replaced benchtop CNC equipment to the local K-12 schools.

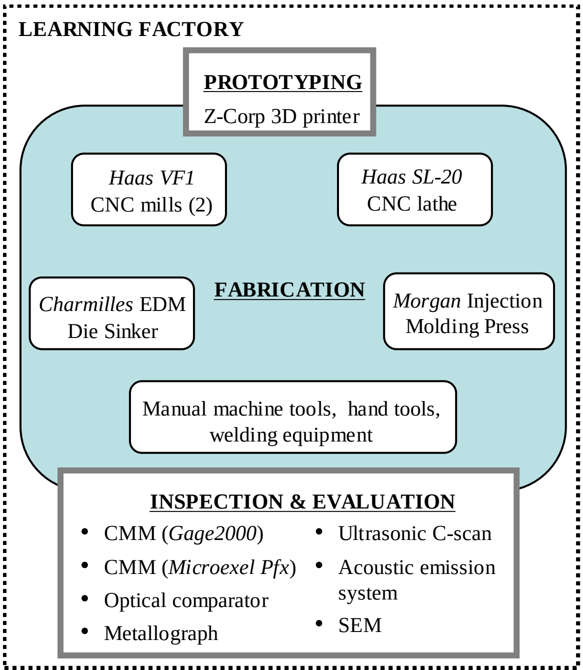

FIGURE 1
NEW *LEARNING FACTORY* FACILITIES AT BUCKNELL UNIVERSITY.

MIDDLE SCHOOL TECHNOLOGY EDUCATION

The Pennsylvania Academic Standards define technology education as that which teaches students to use tools, materials, processes and systems to solve technical problems and provide some benefit to humankind [6]. This education involves a broad spectrum of knowledge and activities. Effective programs combine knowledge of content, process, and skills to provide students with a holistic approach to learning, engage students, and promote an understanding of technology and its relation to science. The Pennsylvania Science and Technology standards divide technology education into three categories, including Biotechnological, Informational, and Physical Systems. While the biotechnological systems are often covered within the science curriculum, the technology education covers material defined within informational and physical systems. Within this context, the main strands of content material defined for inclusion in grades six through eight are described in Table I.

The related state standards emphasize the need to present and explain these topics to middle school students, while the application of knowledge is not expected until high school. This project, however, is based on the demonstrated effectiveness of augmenting lecture and class discussion with laboratory experiments and hands-on activities [7]. Consequently, the described curriculum and project-related enhancements place an emphasis on applying knowledge and learning through participation, exposure, and experience.

TABLE I
MIDDLE SCHOOL TECHNOLOGY EDUCATION CONTENT

Informational Systems	Physical Systems
Computer-Aided Drafting / Design (CADD)	Computer-Aided Manufacturing (CAM)
Graphic Communications	Construction
Engineering / Design Systems	Engineering / Design Systems
Multimedia Technology	Manufacturing
Web Page Design & Publishing	Materials Processing

I. Donald H. Eichhorn Middle School

Technology education offers unique opportunities to apply numerous academic concepts through practical, hands-on applications. As a required component of Pennsylvania education, exposure is ensured for all students. Unfortunately, representing only one element of a comprehensive curriculum, there is a relatively small amount of time for the direct instruction in the use of technology tools. For this reason it is important to optimize the technology curriculum to meet student needs, and it is essential to avoid spending time teaching students what they already know. These objectives are best met with the participation of highly motivated and capable teachers who are in possession of reliable information concerning expectations for student technology proficiency. The described curricular enhancements begin with this in place and benefit from an educational environment that is often difficult to secure.

Before the start of this project, the technology education at the Donald H. Eichhorn middle school had progressed to the stage presented in Table II below. Each student participates in a technology course during one marking period, or quarter, of each of their three middle school grades (6-8). Thus, the grade-based curriculum described in Table II, must be completed in twelve to thirteen weeks, and repeated by the teacher four times per year. Each grade's technology course is composed of three application modules, including website design, computer aided design, and construction. Within every module, a hands-on project is incorporated to provide the students with the opportunity to learn through experience.

ENHANCED MANUFACTURING COMPONENT

Recognizing the strengths of the middle school technology program already in place, and the skill and enthusiasm of the involved educator, plans were made to develop a manufacturing component for the eighth grade curriculum.

Because the NSF-CCLI funding allowed for the purchase of new industrial-size computer-numerically controlled (CNC) machines, the university was able to donate two of the original benchtop CNC milling machines to the middle school. Access to this equipment immediately facilitated a wide variety of exciting new educational experiences for the middle school students. The most promising ideas included: (1) Curricular enhancements, (2) In-school clubs, (3) Technology Student Association (TSA) competitions, (4) After-school outreach programs, and (4) K-12 educator training. It was determined that the most valuable first step would be to enhance the existing curriculum to include a manufacturing engineering component to which all students would be exposed.

TABLE II
D.H.EICHHORN MIDDLE SCHOOL TECHNOLOGY EDUCATION CONTENT

Sixth Grade		
1	Module	Introduction to Website Design
	Software Tool	Hypertext Markup Language (HTML)
	Hands-on Project	Create simple website.
2	Module	Introduction to Computer-Aided Design
	Software Tool	SolidWorks
	Hands-on Project	Interpret isometric view; Create solid model
3	Module	Construction
	Materials & Tools	Balsa wood; Simple hand tools;
	Hands-on Project	Design and construct a balsa wood bridge
Seventh Grade		
1	Module	Intermediate Website Design & Publishing
	Software Tool	Adobe Dreamweaver
	Hands-on Project	Create website including animation
2	Module	Computer-Aided Drafting & Design
	Software Tool	SolidWorks
	Hands-on Project	Interpret 2D drawing; Create solid model
3	Module	Construction & Assembly
	Software Tool	SolidWorks
	Materials & Tools	Pine wood; Wood cutting saws, tools, etc.
	Hands-on Project	Design collapsible bench; Construct bench;
Eighth Grade		
1	Module	Advanced Website Design & Multimedia
	Software Tool	Adobe Flash, Fireworks
	Hands-on Project	Create dynamic website with movie
2	Module	Computer-Aided Design
	Software Tool	SolidWorks
	Hands-on Project	Create 3D solid model of CO_2 car body
3	Module	Intermediate Construction
	Materials & Tools	Balsa wood block; Hand cutting tools;
	Hands-on Project	Carve wooden CO_2 car; Sand; Paint;

Because there was no room in the curriculum for the inclusion of an additional module, a plan was developed to replace the eighth grade *Intermediate Construction* module with a Computer Aided Manufacturing (CAM) experience. The original eighth grade *Intermediate Construction* module had been integrated with CAD activities to simulate the design and manufacturing tasks involved in a CO_2 powered, model car racing competition. Students first designed their car geometries and created the associated solid models using SolidWorks® software. Two-dimensional design drawings could then be generated from their solid models as well. Students then transferred their designs onto a piece of balsa wood stock by hand sketching. Axle holes were drilled, and rough shaping was done with a band saw (Figure 2). Fine shaping was then completed with hand files and sand paper. The car was subsequently painted and then assembled with the wheels.

In an effort to make a seamless transition into the curriculum, the planned manufacturing opportunity was established as a more technically advanced means by which to fabricate the students' CO_2 cars. The developed *CAM* module would begin with the same data as the *Intermediate Construction* module, but progress with an introduction to computer-aided manufacturing software, the basics of fixturing and workholding, computer-numerically controlled machining, and basic machine safety principles.

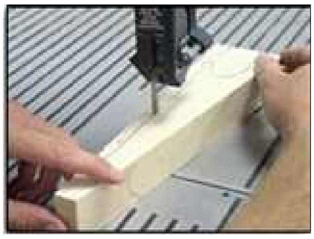

FIGURE 2
BAND SAW ROUGH SHAPING A CO_2 CAR

IMPLEMENTATION SCHEME

The plans to integrate a manufacturing engineering component within the middle school technology curriculum began to be implemented in the summer of 2005.

I. Phase 1: Equipment Donation and Training

Two CNC milling machines, Light Machines Corporation: Model proLight1000, were donated to the middle school (Figure 3). These machines are benchtop units, requiring little space, yet offering enough power to cut polymers and wood efficiently. Each has a range of travel of 12 inches in X, 6 inches in Y, and 9 inches in Z. The machine has a 1-hp spindle with a maximum speed of 5000 rpm, and a standard R8 taper for tooling. The university donation included a basic set of end mills, vices, tool holders, collets, and a quick-change tool system.

FIGURE 3
PROLIGHT CNC MACHINING CENTER

Once the equipment was donated and installed, the university faculty member and the middle school educator met to organize machine training. With the help of a university technician, the middle school teacher was trained in the basic operation of the CNC milling machine.

II. Phase 2: Software Selection

The next phase was the selection and purchase of computer-aided manufacturing (CAM) software. Because the middle school curriculum already included an extensive computer-aided design (CAD) component with the use of SolidWorks, it was a logical decision to use SolidCAM® software for any manufacturing needs. SolidCAM is fully integrated within SolidWorks, allowing the definition of all machining operations, and the calculation and verification of all tool paths, without leaving the parametric SolidWorks assembly environment [8]. Additionally, in the event of required design changes within SolidWorks, all created CAM operations are automatically updated.

III. Phase 3: CAM Module Development - Software

The developed *CAM* module was to begin with the same data as the previous *Intermediate Construction* module, i.e. with a solid model of the student-designed CO_2 car. With their solid model as input, students now use the CAM software to create the program needed to run the CNC machine. The software steps are outlined in Figure 4 below.

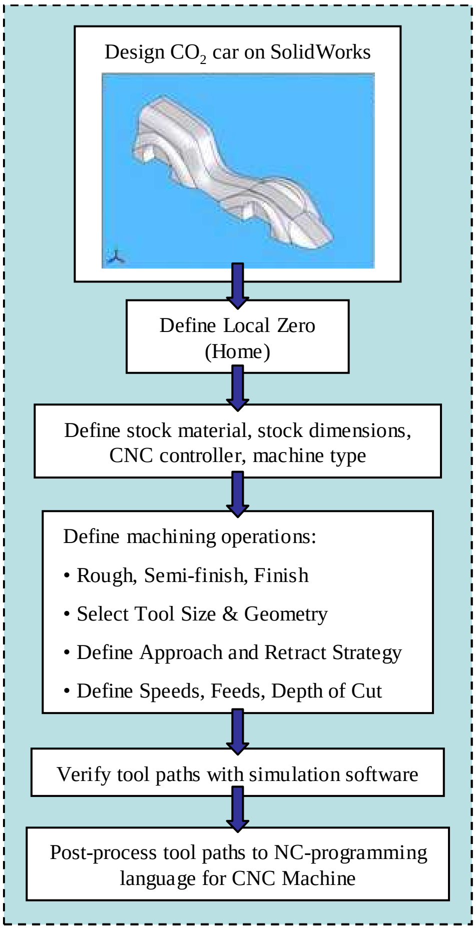

FIGURE 4
SOFTWARE TASKS WITHIN THE *CAM* MODULE

The SolidCAM software inputs the computer model of the student-designed car and first requires the establishment of a local zero or coordinate system. This zero serves as a reference from which all of the tool path coordinates are generated. Subsequent steps include the definition of the piece of raw stock to be machined (Figure 5), the material to be cut in order to generate the designed car, the tools to be used, and the machine parameter settings, such as cutting speed, feed, and depth of cut. All of these items are entered in a simple and user friendly environment. The final software tasks include the graphical verification of the created machine tool paths, and the post-processing of tool paths into the appropriate CNC machine language.

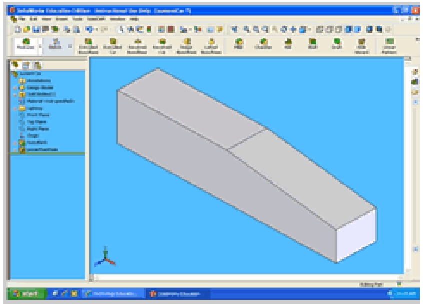

FIGURE 5
STANDARD RAW STOCK

IV. Phase 4: CAM Module Development - Hardware

Once the tool paths have been generated, verified, and post-processed within the SolidCAM software, the students send their programs over to the CNC machine controller and prepare for the physical machining of their cars. This portion of the educational experience is carefully monitored for safety purposes. The CNC machines are equipped with a safety shield that, when open, disables the functioning of the machine spindle.

A jig has been fabricated to locate the stock to ensure compliance between the software-defined local zero and the machine zero. Two bolts pass through the jig and into the stock to allow for quick and accurate locating and securing of the stock to the machine table. Because each piece of raw stock used for the CO_2 car project is identical in size and shape, i.e. 9.0 inches long x 2.0 inches high x 1.65 inches wide as shown in Figure 5, the fixture ensures that the machine zero will always be at the same spot relative to the stock. As a result, the Z-zero does not require resetting between the machining of different cars. Instead, a tool library is set up initially to indicate the Z-offset of each end mill that may be used during the machining process.

Once the stock is locked into place, the ProLight CAM software is used to open the CNC program created in SolidCAM. The program is initially run in single-step mode. This is done for the first two or three blocks of code in order to allow for the visual verification that the machine zero does in fact coincide with the local zero used during CNC code generation. Once the teacher has ensured that the code is being interpreted properly, the program is continued in full operational mode and the rough shaping of the car is completed (Figure 6).

FIGURE 6
MACHINING OPERATION

Although each car is different, most take approximately fifteen minutes to machine. Each student monitors the machining of his/her own car and is prepared to stop the machine spindle in the event of an emergency. Upon completion on the CNC machine, the student removes the car from the fixture and begins the process of fine shaping and finishing. This typically involves filing, significant hand sanding for a smooth surface, and repeated layers of gluing, painting, and fine sanding until the desired finish is achieved. Finally, the wheels and axles are assembled with the car. An example of a CO_2 car completed in this fashion by an eighth grader is seen in Figure 7 below.

The CAM educational module is completed with a culminating race between pairs of cars created by the students.

FIGURE 7
COMPLETED CO_2 CAR

OBSERVATIONS AND EVALUATION

Because the described activities were first implemented in academic year 2006-07, and have evolved during the course of the year, formal assessment is not complete at the time of this writing. Evaluation of the curricular impact of the described activities will be a crucial component of the project. To date, consideration has been given to how the learning objectives match the to K-12 Pennsylvania state education standards. Due to the emphasis on engineering content, it is possible that the learning objectives may also be matched to science and/or mathematics standards, in addition to technology education [9]. Based on the educational objectives and the standards, specific performance criteria are being developed. An effort will be made to create direct assessment tools for the most important course outcomes. In addition, the authors are developing a student perception survey to be placed on the middle school Technology Education web site.

At the present time, several observations can be made. First, the SolidCAM software has proven to be appropriate for the defined application. In addition to the benefits of being fully integrated with the SolidWorks package, SolidCAM provides a vast library of standard programmed features. This allows for the feasible creation of the tool paths to machine a CO_2 car without the need for complex customization by students or teacher. It enables the students to learn the capabilities of CAM software without experiencing many of the potential frustrations that can occur with more complex parts and programs. Educationally, it teaches the students the basic CAD/CAM process, i.e. using a CAD solid model of a part to develop the necessary CNC machine code with which to manufacture it. Also prevalent in industry today, it presents the students with the idea of virtual or computer-aided verification of the machining process prior to the actual cutting on the CNC machine.

The CNC machining process has been very favorably reviewed by the eighth graders. Many marvel at the technology and most are able to appreciate the enhanced capabilities it offers in regard to the achievable complexity of their CO_2 car designs. The machined cars are often much more intricate than those created totally by hand. The capabilities of the CNC machining process have allowed the students to realize most any design. Many cars possess complex contours, large voids, and thin sections generated with near prefect symmetry. The availability of the CNC machines has proven instrumental in encouraging the creativity of many students. Ultimately, the ability to assess the performance of their individual car designs in the culminating racing event serves to motivate the students to strive for excellence. Even the most reluctant learner is often inspired and excited by the hands-on nature of this module.

The resulting impact of the described activities on future career choices will not be clear for some time. When questioned, the current students do express interest in the CAD/CAM process, and convey enthusiasm in regards to the technology and the possibility of similar experiences in the future. Watching the CNC machine cut the product they have designed is very exciting for any student. The hope is that this exposure will have a lasting impact on some of the students that might have otherwise not considered engineering as a potential future career path.

ADDITIONAL OUTREACH ACTIVITIES

Although the development and implementation of the new CAM module is the most significant enhancement that has benefited from the university-middle school partnership, several smaller outreach activities have been completed or are planned. One simple way that the university has been able to assist the middle school curriculum is by generating prototypes using layered manufacturing technologies such as 3D printing and fused deposition modeling. One application for these models has been as a visualization tool for students involved in the middle school CAD modules. For instance, it is often the case that a student struggles with the 3D visualization of the part they are attempting to model in Solidworks. To combat this problem, the middle school teacher will export the relevant solid model to STL format, i.e. the data format used as input for layered manufacturing machines. This file is then electronically sent to the university partner and a rapid prototype is generated. The physical prototype is then available to touch, hold, and inspect in order to aid students as they generate computer solid models.

Rapid prototyping technologies have also proved useful in presenting design alternatives to the eighth graders working on the CO_2 car project. In addition, it is planned to generate a rapid prototype of the CO_2 car that wins the final racing competition each marking period in order to create a trophy case for teachers and future students to enjoy. Lastly, all of the equipment in the university Learning Factory is available to the local K-12 students and teachers for demonstrations, special projects, training, and workshops.

SUMMARY AND RECOMMENDATIONS

It is important to reach out to K-12 students to introduce them to engineering concepts so that they might consider future careers that apply mathematics and science. Often this is achieved through engineering outreach programs offered by universities [10]. While many of these programs include exciting technological opportunities, the vast majority of them are extracurricular in nature. As such, they are not a part of the regular curriculum and often reach only a fraction of the student population. This paper describes a partnership between middle school and university that has resulted in enhanced technology education that reaches the entire sixth through eighth grade population in the school district. In this way, the authors believe that this effort will have a higher probability of success in potentially attracting greater numbers of capable students to engineering, particularly females and minorities.

With the apparent success of the current effort, planning has now begun for future collaborations and curricular enhancements. The authors are investigating the purchase of the computational fluid dynamics software that integrates with SolidWorks. The goal is to develop a component of the new CAM module that allows students to test and assess their car designs prior to manufacture. The thought is to create a virtual wind tunnel with the software so that students can visualize the drag that results on their car geometry. The educational objectives would include an introduction to engineering analysis and related design iterations. The plan would be to enhance this educational experiment with a trip to the university wind tunnel to allow the students to see a physical example of the virtual environment.

Lastly, in considering basic ways to improve on the relationship between the K-12 schools and the university, the authors would like to investigate meaningful ways to involve more college students. Realizing that a service learning component to college-level engineering courses is important, the authors would first look to involve students enrolled in relevant courses such as *Manufacturing Processes* and *CAD/CAM*. This involvement could include student presentations of interesting course projects, hardware demonstrations, software assistance and support, and/or basic tutoring.

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