Teaching Hands-On Manufacturing Technology Fundamentals to ME Students at Local Community Colleges

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Abstract

Some Mechanical Engineering departments in the United States currently do not have enough money to support and sustain modern machine shops, composite lay-up rooms, or welding laboratories within their program. Such shops are essential for new mechanical engineering graduates to understand first hand the issues involved in prototyping and product development. These laboratories are expensive to set up and even more expensive to maintain and staff with well-qualified technicians. At Wichita State University (WSU) we have worked out a plan that enables our students to use the laboratories at one of the local community colleges called the Wichita Area Technical College (WATC). In this agreement the students are provided first hand exposure to manufacturing techniques such as machining, welding, and composite blue print reading / fabrication, among other laboratory exercises. The laboratory sessions are taught by WATC instructors with extensive background and training dedicated to the various manufacturing areas. Students will be expected to attend and participate in a Mechanical Engineering seminar series that will expose them to topics such as Ethics, Safety, Environmental Issues, Global Collaboration, Energy Conservation, Entrepreneurial Aspects of Engineering, Engineering Professionalism, Sustainability, Manufacturability, Project Management, and other topics of professional interest and use. Furthermore, students will have opportunities to work as a team on faculty's research project or a creative project of their own. These hand-on opportunities will give Mechanical Engineering students a more insightful appreciation for manufacturing capabilities and limitations, and permit them to coordinate more effectively with engineering technologists to create more competitive products in the world economy.

Introduction

Education of both mechanical engineers and mechanical engineering technologists in the United States can be an expensive in terms of equipment and software requirements. In mechanical engineering (ME) instrumentation laboratories such as Wichita State University ME 533 Mechanical Measurements class, the inventory can include computers, data acquisition hardware and software, and various sensors, with experiments covering topics such as fluid dynamic system response, temperature and pressure measurement, strain gage measurements, vibration measurement, as well as in-house developed or purchased system level experiments such as flowmeter experiments, thermal conductivity and mechanical system response. To

maintain educational relevancy, such experiments and equipment must be reviewed and updated on a continuing basis. In the ME design laboratory, design and analysis software must be frequently updated to maintain relevancy for teaching engineering analysis skills. Computers must be updated every several years to keep up with more memory and computationally-intensive design and analysis software tools. For engineering technology students, the curriculum must include acquisition and maintenance of state-of-the-art manufacturing systems such as inspection and computer numerical controlled (CNC) machining. A recent acquisition of donated equipment from Haas Machine Tool equipment consisted of two vertical machining center and a turning center was worth $250,000 [1].

However, even though the focus of each institution is concentrated on a core area (engineering science / design with WSU and applied design / manufacturing with WATC), a basic understanding and familiarity of the manufacturing, measurement, and technology skills taught to WATC students must be understood by WSU ME students in order for them as new engineers to effectively develop marketable product designs. This manufacturing experience is not fully accessible to WSU ME students for their design development activities due to multiple factors including space limitations for equipment and cost of equipment acquisition and maintenance. The focus of engineering education in the U.S. in many cases is centered on teaching theoretical and research-related aspects of engineering science and design, rather than also including teaching practical aspects of product development and construction through hands-on experiences. The need for practical manufacturing skill training as a component of a comprehensive engineering science and design curriculum is recognized by other competitors in the world economy such as China[2]. Although successful understanding of design methods and concepts is a desirable outcome, success or failure in development of a constructed and tested prototype which meets or exceeds the safety and design criteria for the senior design project sponsor provides a more real-world assessment of engineering skill development[3].

If exposure to such manufacturing skills is accepted as a worthwhile component to a mechanical engineer's repertoire of skills, how do engineering schools in the U.S. include them? Many if not most engineering schools do have undergraduate fabrication facilities available. The "Learning Factory" at Penn State University's mechanical engineering department is one facility with established comprehensive opportunities and facilities for practice-based learning of design, manufacturing, and product realization[4]. This proven learning model has been established at other institutions as well over the past decade, with the help of initial National Science Foundation funding and supplemental outside agency funding[5]. At Harvard new students in the Mechanical Engineering department are introduced to mechanical engineering through an applied product design development project[6]. To complete the projects students are introduced to initial engineering science and design concepts, 3-D modeling, as well as prototype development using manual and CNC machining. At Purdue ME students learn integrated design, development and manufacturing experience through construction of a brass hammer with a wooden handle, or an aluminum cardholder[7]. Various manufacturing methods are introduced in development of the hammer, including drilling and milling brass hexagonal block to create the hammer head and create the handle hole, as well as using a lathe to create the handle, and final grinding, polishing and CNC machining operations to complete construction of the hammer. At North Carolina Agricultural and Technical State University fabrication techniques are introduced to students through construction of test specimens to be used in tensile tests in which the students design, conduct, and evaluate the results. CNC programming is introduced to the students to

fabricate the coupons[8]. Finally, at Kettering University, King and El-Sayed studied use of an approach where mechanical engineering students are introduced to fabrication methods partly through integrated manufacturing and mechanical design projects[9]. Students in the Manufacturing Engineering Robotics course worked with students in the Mechanical Engineering Design of Mechanical Components course to design, develop, build, and test robotic grippers. Students learned machining skills in development of the grippers, and had opportunities to learn the various components of product development.

When resources to develop and maintain fabrication facilities are limited, other options are still available. One method is to coordinate facilities between educational institutions with synergistic and complementary objectives in engineering product design and development. The Mechanical Engineering Technology (MET) programs such as the one at the Wichita Area Technical College in Wichita, Kansas combines a unique integration of engineering product design knowledge with appropriate manufacturing systems applications and programming. Objectives of the program include:

- To educate and graduate students with the necessary knowledge and skills to become mechanical engineering technicians proficient in the fundamental applications of science and engineering within the fields of mechanical design and manufacturing systems. Graduates will be able to provide high-level technical support to a variety of industries through the following outcomes:

    - Design various machine components, mechanisms and assemblies
    - Design work-holding devices and fixtures
    - Make preliminary sketches and detailed drawings of machines and their components
    - Take accurate measurements with a variety of instrumentation
    - Apply and perform quality control methods and procedures
    - Utilize current solid modeling and CNC graphical programming software
    - Operate basic machine tools
    - Solve for analytical forces on rigid structures
    - Perform standard material testing procedures, to include stress and strain
    - Write technical reports
    - Solve fluid power calculations and interpret hydraulic schematics
    - Relate electrical controls to the operation of mechanical systems

- To meet the practical application needs of the product design and manufacturing industries within the south central region of Kansas.

The mission of the Mechanical Engineering program at Wichita State University is to:

- Provide students with a broad mechanical engineering education.
- Help advance the mechanical engineering profession.
- Contribute toward the economic development of the state of Kansas.
- Enhance the quality of life in Kansas through teaching, research, and outreach programs

The objectives of the ME program are to:

- Educate students to be successful mechanical engineers in their professions in a global environment.
- Prepare students to pursue life-long learning.
- Prepare students for real-world problems by working on industry-based projects.

As seen in an American Society for Mechanical Engineering (ASME) comparison of programs[10] summarized in Table 1, mechanical engineering program graduates at WSU are involved with development of new technology and products, while the mechanical engineering technology program graduates are involved with application of state-of-the-art methods in development of new technology and products. In industry practice, collaboration of engineering technologists and engineers are a normal part of product development from an initial product idea, design conception through prototype construction, test, evaluation, retest, and redesign, through product production and support. Fig. 1 shows the shared responsibilities of this collaboration. Both disciplines are involved in creating solutions for open-ended design problems but from different parts of the product development cycle, as seen in the figure.
Note that the product cycle development a common area of responsibility in overall design development, which includes fabrication and testing. Since technical schools are mandated to train the work force needed for industry they normally have the latest equipment to train technicians and get them ready for industry.

Table 1: Comparison of Mechanical Engineering and Engineering Technology Programs [10]

Program Overview	**Mechanical Engineering Program**	**Engineering Technology Program**
Attributes of the Program Graduate	Innovator using advanced mathematics, engineering science, engineering principals, and incorporating economic, social, environmental & ethical issues to develop new products/procedures	Implementer of current state of the art applied engineering practices and basic mathematics and science in design, operation or testing of engineering & manufacturing systems
Program Objective	Provide knowledge to design and manufacture state-of-the-art products and systems	Provide knowledge to apply state-of-the-art techniques and designs
Program Emphasis	Developing methods of analysis and solutions for open-ended design problems	Developing methods of analysis and solutions for open-ended design problems
Expertise Objective	Develop conceptual abilities	Develop application abilities
Degree (time)	Bachelor of Science in Mechanical Engineering (4 years)	Associate of Engineering Technology or Science (2 years) Bachelor of Engineering Technology (4 years)

This provides an opportunity for educational collaboration in the area of practical fabrication techniques. Unlike WSU, Wichita Area Technical College has an extensive educational program in manufacturing, including equipment and training in the following areas:

- manual fabrication (hand tools)
- measurement and inspection
- blueprint reading and project layout
- machining operations (lathe, drill, milling)
- computer-controlled machining
- composites fabrication
- welding fabrication (oxy-acetylene, tungsten inert gas (TIG) and MIG welding)

The college also has a dedicated staff of engineering technology professionals with extensive experience in the technology areas in which they teach. For mechanical engineering students this would be of benefit, since these instructors would be able to relate what these future engineers need to know in order to work with engineering technologists in industry. The WATC instructors' main focus is also on teaching applied design and fabrication, whereas in many universities, instructors teach applied fabrication skills as a part of other engineering curriculum which competes for time, space, and resources of the university. A collaborative mechanism to share WSU and WATC resources would avoid duplication of efforts and provide learning opportunities for both WSU and WATC students.

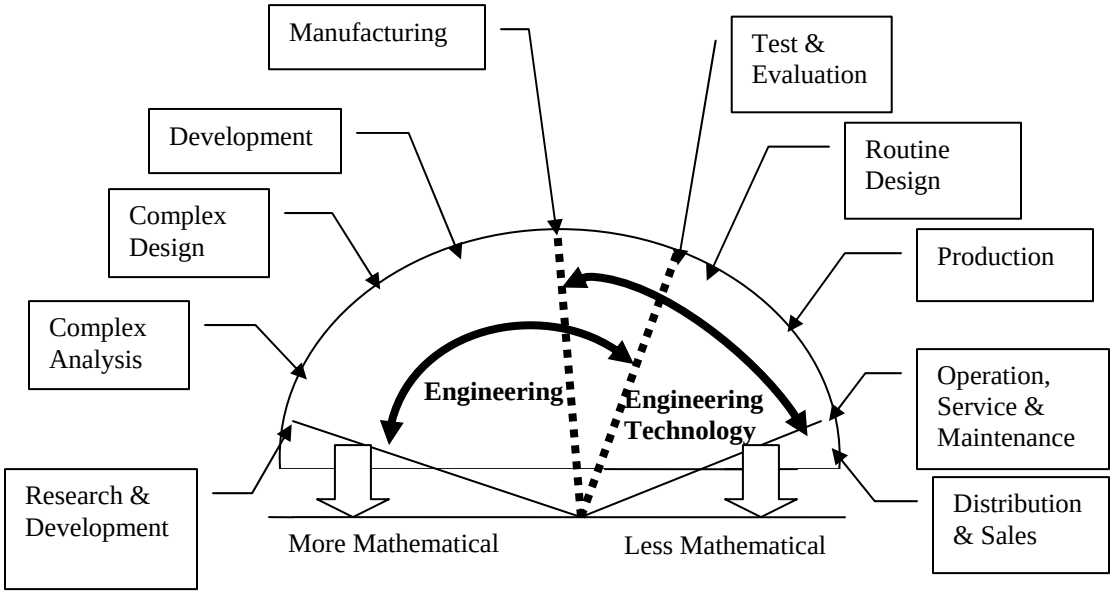

Figure 1. Comparison of Mechanical Engineering and Mechanical Engineering Technology Program Application Areas [10]

Approach

To address the immediate need for improving mechanical engineering student exposure to practical, applied manufacturing fabrication instruction, an agreement was established between the Mechanical Engineering Department at Wichita State University and Wichita Area Technical College. This agreement was part of an overall effort to improve educational opportunities between both WSU engineering and WATC engineering technology students. The intent was to share common facilities, curriculums and development opportunities to control costs and reduce duplication of facilities and equipment. Potential areas of collaboration include:

1. Collaborative Senior Design Project(s)
2. Collaborative efforts on Formula and Mini Baja SAE car development
3. Joint educational research and development proposals and projects
4. Joint technology research and development proposals and projects

The agreement between WSU and WATC enables Mechanical Engineering students to use the laboratories at WATC. All the laboratory experiments will be done at the WATC labs with the appropriate instructors' supervision. The students' performance will be measured by the test given by the technology instructor and the results given to the Mechanical Engineering Instructor. The purpose of this element of cooperation is to provide Mechanical Engineering students at Wichita State University experience in mechanical engineering application skills to supplement their engineering science requirements. This will enable ME graduates to develop effective engineering designs taking into account manufacturing capabilities and realities. This will also enable more effective training for engineering students working in team, with engineering technologists, in research and development of new products, and process designs. The collaboration will help satisfy some of the ABET criteria for program outcomes as well as address some of the problems associated with the lack of equipment and a workshop in the department.

The Mechanical Engineering students can take a new course (ME 450, Creative Design and Practice) as part of their elective option to learn practical issues in mechanical design, including fabrication methods. The course is currently taken by ME juniors in the program who do not have this experience, but it is anticipated that the course will be taken also by sophomore-level students who are interested in getting a practical starting foundation in mechanical engineering. In addition to design lectures there will be weekly Mechanical Engineering Seminar Series Lectures coordinated by the department for the university for which students have to attend. In these lectures, the department will have speakers for various engineering-related topics such as Ethics, Safety, Environmental and Global Warming and Globalization issues, Energy considerations, Entrepreneurial Aspects of Engineering, Engineering Professionalism, Sustainability, Nanotechnology, and other scientific topics. The students will be required to write summary reports on the above topics.

Furthermore, additional lectures will include the review of the Fundamentals of Engineering. Preparation of students to successfully pass the Fundamentals of Engineering exam

is encouraged by the university through this class as well as the capstone senior design class, ME 662 Mechanical Engineering Practice. A final exam administered in the senior design class contains many of the topic elements of the Fundamentals of Engineering examination administered through the National Council of Examiners for Engineering and Surveying, as seen in Table 2.

Table 2 Review Topics Covered by the ME 662 Senior Design Final

- Fluid Mechanics
- Heat Transfer
- Automatic Controls
- Measurement & Instrumentation
- Computers
- Stress Analysis
- Mechanical Design
- Dynamic Systems
- Thermodynamics I
- Thermodynamics II
- Energy Conversion & Power Plants

Currently the three main areas of manufacturing familiarization for the mechanical engineering students provided by WATC instructors are in the areas of machining processes, welding processes, and composite fabrication, and were each conducted in the following laboratories:

Machining Processes Laboratory: This laboratory allows students to gain skills and knowledge in various manufacturing procedures and operations including lathe and mill operation as well as an introduction to Computer Numerical Control machining as shown in Fig. 2. The labs includes safety, proper use of hand and power tools, blueprint reading and sketching, precision measuring and layout, setup, operation, clean-up and basic maintenance of the lathe, milling machine and surface grinders and basic introduction to CNC setup and operation.

a) Basic Machining Processes b) Advanced Computer Numerical Controlled Machining

Figure 2. Students learning the machining process.

Welding Laboratory: This laboratory allows students to gain knowledge and skills in cutting, arc welding, MIG and TIG welding and provides some exposure to oxy-acetylene cutting and welding as shown in Fig. 3. The labs includes safety, blueprint reading and sketching, tools and materials used in the various forms of welding, machine adjustments and rod selection, skill requirements for various welding positions, weld testing and certification, fabrication and layout of various welding projects.

Figure 3. Students learning welding processes

Composite Fabrication Laboratory: This laboratory provides students with the skills and knowledge necessary to work in various phases of the composites industry, including process and product design, tool and mold design, product and process manufacturing and quality assurance. Students receive hands-on working knowledge of the manufacturing methods and techniques used in today's composite industries as shown in Fig. 4.

a) Composite Lay-up fundamentals

b) Finished product example

Figure 4. Students learning composite product fabrication

Currently the coordinator for the ME 450 Creative Design and Practice course is the Department Chair Dr. Behnam Bahr, Professor of Mechanical Engineering. Although no formal textbook is currently used, a required reference for the class is the Fundamentals of Engineering Reference handbook [11]. In the required creative design project, students work in groups of three with a professor of their choice. The faculty will be responsible for the oversight of the student final project, and the grade for the project will be given to the instructor of the course. The relationships to ABET Outcomes are defined as follows:

1. The students will be able to practice on modern equipments to machine tools, and joining processes for both metal and composite (Criterion k)

2. The students will be able function on a team for their research/project (Criterion d, c)
3. The student will be able to consider the ethical, safety, environmental, and other issues to consideration when they design their components. (Criterion h and j)
4. Students are required to prepare for the Fundamental of Engineering Exam by their own with some review in the class (criterion f, i)
5. The students will be able to communicate effectively through written report. (Criterion g)

Student Feedback

On the last day of the course evaluation was distributed to all students to allow them to evaluate this new course. Overall, students were pleased with this session except the amount of class time. Similar to the welding session, students agreed with all aspects expect the amount of class time. In general, students were very pleased with the course. However, students indicated in both the evaluation and in their comments that they would like to have more time. The comments are given below for each question:

Question 1: What were the strengths of this course?

"It's a very good intro into the tools of the trade."

"Provides an awareness to the practical areas of my career."

"Great projects."

"Practical knowledge that can be used in life. Good instructors."

"I think one of the best things was the experience of the instructors. Also loved making projects."

"I liked the open ended creative project."

"The practical application was by far the best part."

"The strengths were the hands on/eyes on experience that we received. "

"It gave a preparation and good tool in dealing (with) my senior design project."

"Provide information and knowledge about industrial and manufacturing process. "

"Really enjoyed the welding. Machining was also very useful and interesting. "

"Welding and machining provided good basic knowledge. Composites some knowledge but can be very complicated and application specific"

"Good facilities that WATC provided for students."

"Good coursework. Excellent teachers."

Question 2: What suggestions do you have to improve the course?

"More focus on the capabilities of the machines and not the syntax of the CNC machine. "

"I did not have enough time for welding. I loved that course and wish I had more practice time."

"Focus more on the practical side of the course. Papers and assignments should relate to the thing we learned in the shop. "

"Everything is good, instructors are friendly. We should do more practical things in composites class. "

"My suggestions would only apply to the WSU lecture sessions-if you want to make the FE an integral part of the course; the lecture session should be a refresher of the subjects on the test."

"For WSU ME students, how to design these considerations in place-maybe make them read a print."

"Have more practical time available."

"Composites section is a little lacking."

"Increase lab times for welding and machining."

Question 3: Please feel free to share any additional comments or suggestion you would like to make.

"Except for insufficient amount of classes overall, (it) was fantastic."

"Everything was perfect!"

"Great facilities and great teachers"

"We should have more welding session. The machining class is good, should cover more things in composites class. Thank you. "

"The more focus on practical manufacturing methods, the better. ME courses already provide plenty of theory. Good practical knowledge is important for engineers."

"Great job!"

"I only wish we had more time. "

Lessons Learned

Evaluation of students' feedback on these questions indicated that overall the students thought the manufacturing methods exposure was useful in their engineering education, but was not sufficient to develop the skills. To an extent this was expected as the purpose of the WATC

sessions was to provide an overview of the manufacturing methods to guide them in design practice and perhaps do some basic manufacturing tasks, but not to fully develop the skills, which would require taking the actual WATC curriculum. However, based on the students' feedback, the lab session has increased from two hours to three hours. Several students indicated satisfaction with the instructors' teaching and training.

The students also enjoyed the open-ended design projects compared to theoretical and conceptual aspects of engineering practice. As with other courses in the department, the course design is under a continuous improvement process. One potential option is to further develop this course as an open design definition course tied to the senior design course ME 662 Mechanical Engineering Practice. This would provide more time for project design definition and development, as well as prototype development, debug, and design revision. Overall it appeared the students felt it was important to include understanding of practical manufacturing skills in the educational mix of topics needed in a mechanical engineering education. Further experience with this course will help determine what other aspects of technical topics to include in the mix.

In the global world economy, new mechanical engineers are expected to be grounded in practical manufacturing fabrication, who can understand the pros and cons of various manufacturing technologies when developing their product and process designs. For Mechanical Engineering departments with short or long term limited funds and a need to provide their students a more comprehensive fabrication background, this type of engineering and engineering technology department collaboration can help fill this gap.

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Biographical Information

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George Gray is an instructor of Mechanical Engineering Technology at Texas Tech University in Lubbock, Texas. He is the former Engineering Dean of the Applied and Engineering Technologies Division at WATC in Wichita Kansas and former faculty member at Texas State Technical College. Mr. Gray holds a Master of Science degree from Texas A&M University, and has worked extensively within the engineering and manufacturing field. He has background and research interests in industry/engineering technology/engineering school collaborations.