AC 2007-537: DEVELOPMENT OF A MANUFACTURING PROCESSES COURSE FOR A BSE PROGRAM: SIGHTS, SOUNDS, SMELLS, AND STUDENT LEARNING

David Farrow, University of Tennessee-Martin

David Farrow is an Assistant Professor of Engineering at the University of Tennessee at Martin. He received B.S. and M.S. degrees in Mechanical Engineering and a Ph.D. from the University of Texas at Arlington in 1989, 1990, and 1995, respectively. Dr. Farrow has taught courses including solid modeling, mechanical vibrations, automatic controls, automated production systems, instrumentation and experimental methods, and now manufacturing processes at the University of Tennessee at Martin for five years.

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Abstract

The development of an upper division elective course in manufacturing processes for a Bachelor of Science in Engineering degree program is presented. The development is justified via the program history and by recalling traditional manufacturing and mechanical engineering educational curricula. The course's relationship to program educational objectives, which map into ABET assessment criteria, and how the course relates to other courses in the program are presented. Specific expected educational outcomes identified for the course are also presented. The text selection process is included. The course scope, prerequisite coursework, lecture topics, content delivery methods (including multimedia tools), activity scheduling, lab component issues, and incorporation of industrial tours are addressed. Assessment of student learning via in-class exercises, short papers, tour journals, and exams is discussed. Results of a student survey concerning the first course offering are presented. The necessity of the course in light of the increasing emphasis on engineering design education and globalization is argued.

Institution and Program Overview

The University of Tennessee at Martin (UT Martin) is a primarily undergraduate institution offering an ABET-accredited Bachelor of Science in Engineering degree with concentrations in civil, electrical, industrial, and mechanical engineering disciplines. Implemented on a semester schedule, the degree program consists of a 50-hour core curriculum for all concentrations, 51 hours of general education requirements, and 27 hours of concentration-specific upper division curricula, including 9 hours of electives. Thus, the degree comprises 128 credit hours. Passing the NCEES Fundamentals of Engineering Exam is a further requirement for graduation. There are approximately 250 students and ten full-time-equivalent faculty members.

Need for Course

To provide wider educational breadth for upper division mechanical and industrial concentration students, engineering department faculty in those concentration areas determined that a course in manufacturing processes would be a beneficial addition to the courses offered for those two concentrations. The mechanical concentration upper division elective courses comprised energy systems, signals and systems analysis, automated production systems, and manufacturing systems, which was on the books but had not been taught recently. Manufacturing systems' course number was retained and the course title and description were updated to describe what is now titled ENGR 474 Manufacturing Processes, the subject of this paper. The industrial concentration upper division electives comprise human factors, introduction to management, operations management, and design of experiments. Automated production systems and (now) manufacturing processes are both required upper division courses for the industrial concentration. This new ENGR 474 Manufacturing Processes course was initially offered in spring 2006 as an upper-division elective for the mechanical concentration and as a required upper-division course for the industrial concentration.

Academic and Industrial Backdrop

A broad exposure to fundamental manufacturing processes can be important to mechanical and industrial engineers. A mechanical engineer's design can be influenced by how that design may be realized by appropriate manufacturing processes and machines. An industrial engineer would draw upon knowledge of manufacturing processes and machines for the layout of manufacturing facilities. In either case, interacting with manufacturing engineers may be involved.[1] With the increased and continuing emphasis on engineering design in engineering education[2] and the practice of concurrent engineering[1], at least a broad exposure to fundamental manufacturing processes would seem to be relevant for students studying mechanical and industrial engineering. Furthermore, any subsequent study of manufacturing engineering, design for manufacturability, and/or manufacturing process engineering could logically draw upon a broad first course in manufacturing processes such as the one described in this paper.[1] As noted previously, the UT Martin Engineering program was essentially lacking any such course, hence the development of ENGR 474 Manufacturing Processes, the subject of this paper, to better prepare mechanical and industrial concentration graduates of the program with respect to manufacturing.

The author/instructor recalls taking a required manufacturing processes course in an undergraduate mechanical engineering program and wanted to develop a course with similar content and enhanced opportunities for student learning. The enhancements of in-class video and industrial tours were incorporated into a new course on manufacturing processes. While conceding that neither of these two pedagogical features is by any means original, the author/instructor was interested to read of a similar effort in the literature. Incorporation of industrial tours into a manufacturing processes course has yielded, in at least one fairly recent work by Vollaro, survey data that suggested that "…most students prefer to utilize a kinesthetic and/or visual sensory modality in learning new information."[3] Student survey results from the initial offering of the new UT Martin course described in this paper also suggest positive benefits to student learning from videos and industrial tours. These survey results are presented later.

Other recent works discuss how manufacturing engineering, related disciplines, and engineering education have been expending much effort to chart a course into the increasingly competitive, globalized, and outsourced 21st century. In an overview of how outcomes-based engineering education, the engineering profession, and industry might interact in the 21st century, Todd *et al*[4] argue for whole new manufacturing engineering programs and increased manufacturing curricula in traditional engineering education. Other works concerning manufacturing engineering education describe the implementation of an interdisciplinary manufacturing engineering program by Liou[5] and brainstorming session results from a manufacturing engineering education conference by Waldorf *et al*.[6] At least one institution has creatively combined manufacturing processes and materials science topics when faced with reducing the number of mechanical engineering degree credit hours, as described by Griffin and Creasy.[7] More traditional than the course they describe, the course presented in this paper has the designation of upper-division requirement/elective and is supported with a traditional, required, and separate materials science course and lab. Implementation of this manufacturing processes course at UT Martin is a small step in the direction of calls for increases in manufacturing curricula and programs, and it gives students of the UT Martin engineering program an opportunity to learn about manufacturing processes and how important manufacturing is to their careers and to the global economy.

Course Description and Design

The philosophy of the course is to expose upper division mechanical and industrial concentration students to fundamental manufacturing processes, primarily involving metals. Concepts, terminology, and technology, rather than analysis, are emphasized. Video footage of vintage and modern manufacturing processes and equipment is incorporated into essentially every lecture period to help illustrate, and increase students' comprehension of, the course material. Furthermore, multiple industrial tours are scheduled and conducted to get the students out in the field to see, hear, occasionally smell, and subsequently reflect upon and report on real-world manufacturing processes, equipment, and enterprises. These two pedagogical aspects of the course are included specifically to address the needs of students who prefer visual and/or sensing learning modes, both of which are quite common among engineering undergraduate students.[8, 9] The course is described in the UT Martin undergraduate catalog as follows:

ENGR 474 Manufacturing Processes (3) An introduction to the processes used in manufacturing to convert raw materials into finished products. Processes covered include casting, molding, forming and shaping, material removal, and joining. The mechanical and metallurgical fundamentals of material deformation processes will also be covered. Two lecture hours and one three-hour lab. *Prereq: ENGR 220 and 310.*

The course is designed to address a subset of the Department of Engineering program educational outcomes, which have been designed to map into ABET assessment criteria.

Following the course syllabus, the course addresses these outcomes as follows:

"At the time of graduation, graduates will have an ability to":

- Formulate and perform basic engineering analyses and economic assessments.

  By understanding relative costs of available processes that could be employed to realize a design, students will know to try to minimize costs, while maintaining design integrity, at the manufacturing stage of product life.

- Design a system, component, or process to safely meet desired needs that incorporate realistic constraints.

  By understanding that how something is made can influence the design, students will know to think ahead to how their design might be made, thus taking the first steps toward design for manufacturability considerations.

- Visualize components in a system and prepare and interpret schematics of the system.

  Through exposure to textbook figures, video footage, and industrial tours, students will gain knowledge of manufacturing machinery, manufacturing environments, and their inner workings and system-level relationships.

- Communicate effectively using standard industry terminology through hand-written technical documents, formal written documents, and oral presentations.

  By making writing an important student deliverable though the use of tour journals, optional short papers, in-class exercises, and exam questions, students will acquire more practice in writing engineering communications.

- Possess an educational background necessary to understand the global context in which engineering is practiced, including a knowledge of contemporary issues related to science and engineering, the impact of engineering on society, and the role of ethics in practicing engineering.

  The contemporary political, economic, and ethical issues related to manufacturing often come up on industry tours, and while not formally addressed in the lecture, the students' attention is directed to them during the course.

Specific Expected Educational Outcomes of the Course

Upon completion of the course, the student should be able to understand and describe the following (primarily metallic) manufacturing processes, why and when they are employed, their advantages and disadvantages, and how they affect the material properties of the manufactured product:

- Metals casting, via expendable and reusable molds
- Powder metallurgy
- Forging
- Rolling
- Cold drawing
- Extrusion of metals
- Metal shearing and forming
- Welding, brazing, and soldering
- General machining and cutting tools
- Turning, boring and facing
- Drilling and related operations
- General milling
- Broaching and sawing
- Electrical discharge machining
- Grinding, finishing, and surface treatment of metals
- Plastic injection molding, blow molding, and finishing
- General rapid prototyping

Curricular Sequence

The prerequisite courses for this course in manufacturing processes are ENGR 220 Strength of Materials, and ENGR 310 Engineering Materials, as shown in Figure 1.

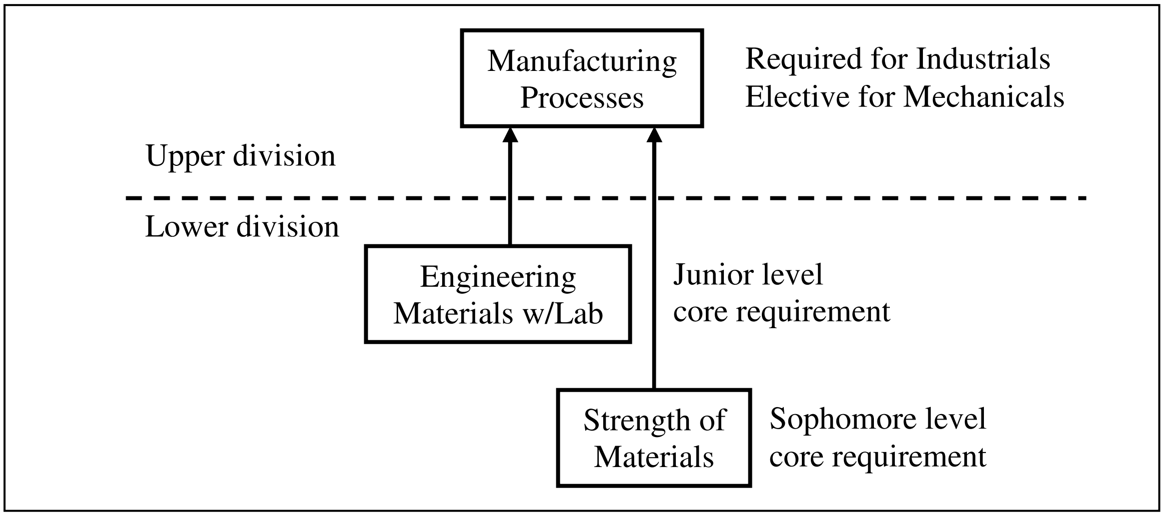

Figure 1. Course Relation to Other Courses

Thus, students are expected to have fundamental knowledge of engineering material properties, both macroscopic and microscopic, before taking this manufacturing processes course. The ENGR 220 course is a typical first course in engineering solid mechanics. The ENGR 310 course has a laboratory component which includes activities on materials testing and processing of materials to affect properties. Both of these courses are core program required courses.

Text Selection

After reviewing several excellent textbooks, the author/instructor deemed it beneficial to use a text that placed more emphasis on processes than on analysis. Thus, *Manufacturing Processes and Materials, Fourth Edition,* by Schrader and Elshennawy[10], was selected as the required course text. Published by the Society of Manufacturing Engineers (SME); the text ISBN number is 0-87263-517-1.

Course Schedule

The course meets twice weekly for a 50-minute lecture and once weekly for a three-hour lab period. The topics covered are listed in Table 1. The lectures consist primarily of PowerPoint summations of the topic(s) in concert with relevant video footage, the timing of which is shown in Table 2. The course flow is generally in the topical order of Schrader and Elshannawy. Students are expected to have read the relevant topical chapter(s) prior to lecture so as to facilitate any classroom discussion and/or in-class exercises.

Table 1. ENGR 474 Manufacturing Processes Lecture Schedule

Date	*Text Chapters*	*Lecture Topics*	*Tape* N = No	*DVD* N = No
Jan 18	None	Syllabus / Overview of course	N	N
Jan 23 Jan 25	1,2 8	L1 Introduction to Manufacturing / Exercise L2 Metals Casting Expendable Molds	N ✓	N N
Jan 30 Feb 1	9 10	L3 Metals Casting Reusable Molds L4 Powder Metallurgy	N ✓	✓✓ ✓
Feb 6 Feb 8	11	L5 Hot and Cold Work – Forging In-class Exercise	✓ N	✓ N
Feb 13 Feb 15	11	L6 Rolling, Cold Drawing, Extrusion EXAM I (in Lab)	✓ N	N N
Feb 20 Feb 22	12 12	L7 Metal Shearing L8 Metal Forming	✓ ✓	✓ ✓
Feb 27 Mar 1	13 14	L9 Welding L10 Other Cutting and Joining	✓ ✓	✓ N
Mar 6 Mar 8	17 18	L11 Introduction to Machining L12 Turning, Boring, Facing	N ✓	✓✓ ✓
Mar 13 Mar 15		NONE – Spring Break		
Mar 20 Mar 22	 20	In-class Exercise L13 Drilling and Allied Operations	N ✓	N ✓
Mar 27 Mar 29	 21	EXAM II (in Lab) L14 Milling	N ✓	N ✓
Apr 3 Apr 5	22 22	L15 Broach and Saw L16 Electrical Discharge Machining	✓ ✓	N ✓
Apr 10 Apr 12	23,24	L17 Grinding In-class Exercise	✓ N	✓ N
Apr 17 Apr 19	25	L18 Finishing EXAM III (in Lab)	✓ N	N N
Apr 24 Apr 26	26 7.3-7.5	L19 Surface Treatments L20 Plastics	✓✓ N	N ✓✓✓
May 1	None	Course wrap up	✓	N

Comprehensive final exam as per university schedule.

Video Footage

For the initial offering of the course, the video footage was a blend of old and new. The old footage consisted of VHS videotapes dating from the early 1980s which were still serviceable and available from the university library. These tapes contain footage provided by General Electric Aircraft Engine Division (Cincinnati) for a Manufacturing Materials and Processes Videoprograms Series produced by Lynn Technical Training Operation and distributed by their Technology Marketing Operation. The tapes were originally obtained from the SME Manufacturing Engineering Education Foundation by what was then the School of Engineering and Engineering Technology at the university.

Table 2. ENGR 474 Manufacturing Processes Video Content

Lecture Topic	*VHS Video (min.)*	*Sampler DVD (min:sec)*
L1 Introduction	n/a	n/a
L2 Metals casting exp.	Casting metals (28)	n/a
L3 Metals casting reuse.	n/a	Casting (6:15) Die casting (6:54)
L4 Powder metallurgy	Powder metallurgy (14)	Powder metallurgy (7:13)
L5 Hot and cold work – Forging	Forging (19)	Forging (4:59)
L6 Rolling, cold drawing, extrusion	Rolling (11)	n/a
L7 Metal shearing	Sheetmetal (7)	Sheetmetal shear and bend (4:03)
L8 Metal forming	Sheetmetal (12)	Sheetmetal stamp dies and process (6:26)
L9 Welding	Welding (15)	Welding (4:22)
L10 Other cutting and joining	Joining (9)	n/a
L11 Intro. to machining	n/a	Workholding (3:42) Cutting tools (7:20)
L12 Turning, boring, facing	Lathe (17)	Turning and lathe basics (4:50)
Spring break	n/a	n/a
L13 Drilling and allied operations	Drill bore (25)	Basic hole making (5:01)
L14 Milling	Milling (9)	Milling and machining center basics (5:31)
L15 Broach and Saw	Broach/Shape (16)	n/a
L16 EDM	EDM (13)	EDM (3:57)
L17 Grinding	Abrasive mach. (11)	Basics of grinding (3:01)
L18 Finishing	Abrasive flow mach. (11)	n/a
L19 Surface treatments	Coating (15) Plating (17)	n/a
L20 Plastics	n/a	Plastic injection mold (6:07) Blow mold (4:57) Plastics finishing (6:58)
Course Wrap up	Rapid prototyping (excerpts)	n/a

The new footage was from an SME "DVD sampler" ISBN 0-471-656704 that previews the modern SME DVD collection. Each preview segment is relatively short compared to the VHS tapes, but provides important material with a clearer picture and sound. This DVD sampler was used initially because the new full-length (nominally half-hour) DVDs had yet to be purchased.

Since the initial offering in the spring of 2006, the university has since purchased, at the author/instructor's request and with library funds, nine of the modern SME DVDs previewed by the sampler for use in this class and for general loan from the library. The purchase of several more of these DVDs will be requested in the next budget cycle. For more information, see http://www.sme.org/videos/. It is the author/instructor's intent to obtain a reasonably complete set of these up-to-date SME DVDs.

In-Class Exercises

The in-class exercises serve as exam reviews and as cooperative learning opportunities for the students. After an initial general review session led by the author/instructor on the material to be covered on the upcoming exam, the students pair off, discuss, and write down answers to questions posed on the chalkboard relating to the material. Typically the questions concern listing the aspects of specific manufacturing processes and/or comparing and contrasting two or more processes. The students turn in written answers for credit as pairs.

Exams

The three exams and the final exam include terminology definitions where the student must write a concise definition or description of ten relevant terms, fundamental statements concerning manufacturing processes that must be marked as true or false, multiple choice problems in which the best proposed answer is selected for a question or statement about manufacturing processes, and short essay questions, in which the student must describe a process in depth or compare and contrast two processes. The weighting scheme for all course components is shown in Table 3.

Table 3. Weighting of Course Components

Component	*Component Weight*
In-Class Exercises	10%
Lab Activities	25%
Exam I.	15%
Exam II.	15%
Exam III.	15%
Comprehensive Final Exam	20%

A standard ten-point grading scheme is used where 90 to 100 = A, 80 to 89 = B, and so forth. The lab component of the course is described next.

Industrial Tours as Lab Learning Experiences

Industrial tours comprised the laboratory component for the initial offering of the course. Visiting local (within one hour's driving distance) manufacturing firms and touring their facilities afforded students with many learning opportunities. The sights, sounds, and occasional smells of real-life manufacturing perhaps are best experienced in person. Table 4 lists the West Tennessee firms, alphabetically by name, which hosted tours for the course. The tours were not tightly coordinated with the lecture schedule, as this was deemed impractical.

The students got to observe many manufacturing processes in various environments, including gear hobbing and generating, drop forging, sheetmetal bending, punching, and drawing, machining of metals, induction melting of scrap steel, continuous casting of steel, structural shape rolling, powder coating of metals, painting, plastic injection molding, plastics finishing, thread rolling, welding, brazing, and soldering. The assembly of complex products was observed, as were varying degrees of process automation, including robotics and PLCs. Assembly lines were toured, and students got to see where and how people contribute to the manufacturing enterprise, from "out on the floor" to "up in the front office".

Table 4. Industrial Tours

Firm	*Location*	*Primary Product*
B&R Gear	Sharon, TN	Gearing
Cutting Specialists, Inc.	McKenzie, TN	Lawnmower Blades
Gerdau Ameristeel	Jackson, TN	Rolled Structural Shapes
Leland-Powell Fasteners	Martin, TN	Threaded Fasteners
Lennox Hearth Products	Union City, TN	Home Fireplaces
MTD Products	Martin, TN	Riding Lawnmowers
Nordyne, Inc.	Dyersburg, TN	HVAC Units
Parker-Hannifin	Greenfield, TN	HVAC Components
Plastic Products Co. Inc.	Greenfield, TN	Injection Molded Parts

Typically the tour group was given an initial talk about each firm by a member or members of the management, engineering, and/or manufacturing workforce. For many students, this was their first experience with real manufacturing environments, particularly the steel mill. Many students were astounded by the scale of its operations. The heat, light, roar, and vibration of induction melting and continuous casting of scrap steel were not common to the students' mostly rural backgrounds (beyond television or the movies, say).

After each industrial tour, students were required to write about the tour experience in a tour journal, using a standard bound lab notebook. Students write one or two pages per tour and have to relate what they experienced on the tour to the course material. The journals are submitted, graded, and returned before the next tour, typically with a one-week turnaround. The journals are relatively quick to grade, as content is stressed over format. Thus, as long as they write legibly, the students typically do well on this activity. Tour journaling is intended to help fix the experience in the students' minds. If a student misses a tour, he or she must submit a short typewritten research paper on a process covered in the lecture. It must be more in-depth, and in this way it substitutes for one tour and a related journal entry. There were a small number of these papers, perhaps ten, over the course of the semester. Most students attended most of the tours. Attendance was recorded at the tour sites.

Student Survey Results

The semester began with 24 students enrolled. One student withdrew, leaving 23 students completing the course. 23 anonymous survey forms were completed at the time of the final exam, the results of which are summarized as follows:

Q1.) Would you recommend more, less, or about the same amount of PowerPoint?

The responses were about evenly split, with 11 (48%) preferring about the same amount and 12 (52%) preferring less PowerPoint. Saturation might have been reached, because no responses indicated a desire for more PowerPoint than was employed. *The author/instructor interprets this as perhaps indicating the need to use less PowerPoint and increase the amount of group activities.*

Q2.) Would you recommend more, less, or about the same amount of video footage?

The responses were six (26%) favoring more video, 14 (61%) preferring about the same amount, two (9%) preferring less, and one (4%) response was left unanswered for this question. *These responses suggest a strong favorable reception of the videos by the students. This was not unexpected, as manufacturing tends to be a very visually-oriented topic, especially in an introductory survey course.*

Q3.) Would you recommend more, fewer, or about the same number of industry tours?

Five responses (22%) indicated a desire for more tours, 14 (61%) thought the number of tours was about right, and four (17%) would have preferred fewer. *A strong favorable reception of the tours by the students was suggested, which was not unexpected.*

Q4.) Would you like to have had traditional homework problem sets assigned?

Four responses (17%) were in favor of homework, 14 (61%) were not in favor of homework, and five (22%) indicated not sure. The latter response option was provided because the students might not have known what such homework might entail. *With all the reading, touring, and journaling, the students were processing much material. Having more than half the class against assigned homework was thus not surprising. The author/instructor will likely assign small infrequent homework sets in the future, because that is an effective learning mechanism for many students, not just the ones who would prefer it.*

Q5.) Would you like to have had a semester project, working in groups of two or three students?

Nine responses (39%) were in favor of small group semester projects, while 11 (48%) were not in favor. Three (13%) were not sure about projects. *That these responses were not incontrovertibly against semester projects came as a pleasant surprise to the author/instructor.*

Q6.) Was the textbook overall a good resource (organization, clarity, illustrations)?

Fourteen of the responses (61%) indicated a favorable impression of the textbook, with seven (30%) indicating a negative impression. Two (9%) indicated unsure on this question. *The textbook will used again, particularly in light of these responses.*

Q7.) Rate the overall contribution of the video footage to your learning:

Only one student (4%) indicated that the video contributed negligibly to his or her learning, while 20 (87%) and two (9%) indicated significant and indispensable contributions, respectively, of the videos to his or her learning. *Again, as in question two, manufacturing can be a very visually-oriented topic, especially in an introductory survey course.*

Q8.) Rate the overall contribution of the industry tours to your learning:

Four of the responses (17%) indicated negligible contributions to learning by the industry tours, while ten (43%) and nine (39%) indicated significant and indispensable contributions, respectively, of the tours to student learning. *This is another strong response in favor of industry tours, as in question three.*

Q9.) Circle which tour was the most beneficial to your learning:

Fully 17 (74%) of the responses indicated Ameristeel (steel mill) as the most instructive tour. There were three (13%) responses indicating B&R Gear as most beneficial, and one response (4%) each for MTD products and Leland-Powell Fasteners as most beneficial tour. One response indicated three beneficial tours: Ameristeel, MTD, and Lennox. *Ameristeel, being a mini-rolling steel mill, was very impressive and on a scale perhaps a little more than what the students were expecting. Certainly, induction-melting of scrap steel was very exciting to witness, as were the long structural shape rolling processes. Students may have confused "beneficial to learning" with "exciting and entertaining", but the author/instructor hopes not.*

Future of the Course

The student reception to the initial offering of this new manufacturing processes course was encouraging to the author/instructor, and some elements will be further improved for the second offering scheduled for spring, 2008. The updated DVDs will substantially replace the older videotapes as previously mentioned. The greater amount of footage may require having the students go to the library and view the tapes on their own time. This will have the benefit of freeing up more lecture time for group activities and discussions, which is desirable. Although the industrial tours will remain the primary focus of the lab component, the author/instructor is considering the inclusion of some elementary hands-on manufacturing activities for the lab, such as rapid prototyping, non-ferrous metals casting, a lathe thread cutting exercise, or perhaps vacuum plastic sheet molding. Equipment suitable for these activities is already available in the engineering laboratories and being used for various projects. Two to four such hands-on activities would further round out this course and provide another mode of learning for students.

Conclusions

A newly implemented manufacturing processes course has been described. The need for the course in light of program history and the engineering discipline were discussed. The relationship of the course to program outcomes and prerequisite coursework were included. The design and implementation of the course were detailed, including industry tours. Student survey results were seen to be generally favorable and future modifications and updates to the course lecture and laboratory elements were outlined. The engineering program curriculum has been strengthened and broadened by the development and implementation of this course and laboratory, as students have been exposed to the important and very broad field of manufacturing processes.

Acknowledgments

The author/instructor thanks the firms listed in Table 4 for their contributions to the education of the students and to the success of the course. Dr. Robert LeMaster, of the UT Martin Department of Engineering, provided textbooks for review, insight into several local manufacturing firms, and suggested the tour journal concept.

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