New Integrated Materials and Manufacturing Course Sequence for Mechanical Engineering Technology

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ABSTRACT

This paper describes a revision to the Mechanical Engineering Technology curriculum at Purdue University intended to more closely integrate materials and manufacturing topics. The newly developed course sequence provides opportunities for emphasizing the relationships between material structure, properties, and applications, and also incorporates a systems approach to manufacturing processes. In addition to explaining the rationale for the course changes, the paper also includes descriptions of some laboratory exercises used to reinforce fundamental concepts and enhance experiential learning.

I. INTRODUCTION

Traditionally, alloy metals such as low grade steel and aluminum have been emphasized as the *materials-of-choice* in most laboratory learning activities associated with manufacturing and materials courses in undergraduate Mechanical Engineering Technology (MET) and Manufacturing Engineering Technology (MFET) curricula across the country. This seemed to be an appropriate approach to engineering technology education until recently, since many of the lucrative careers in engineering technology were found in the heavy manufacturing industries that relied significantly upon the expertise of individuals with backgrounds in metal properties and capital-intensive manufacturing techniques. However, due to industrial outsourcing and the creation of new markets as well as the inception of alternative materials and advanced manufacturing processing techniques, it can now be argued that this emphasis needs to be modified to address new challenges and exploit cutting-edge opportunities.

Today, markets in biomaterials, plastics, green materials, advanced composites and ceramics, and electronic materials have grown disproportional in comparison with those in the traditional metals manufacturing industries [4, 8]. For example, advanced plastic and composite materials have revolutionized the product lines in industries such as sporting goods and orthopedics [3, 8]. Biomaterials manufacturing has been, and will continue to be, an area requiring qualified individuals to work in development, design, and testing to meet healthcare challenges [2, 3]. The integration of green engineering principles and materials into engineering and engineering technology continues to be an initiative of government entities such as the Environmental Protection Agency (EPA) and accreditation bodies like the Accreditation Board of Engineering and Technology (ABET) [1, 5, 6, 9]. In order to be globally competitive, industries that supply products to these markets require individuals that have the proper skills and training in the areas of advanced materials and manufacturing techniques. Thus, without a change in emphasis in these curricular areas, individuals will likely graduate from B.S. MET and MFET programs with an inadequate skill set to meet these current and future opportunities [7].

This paper presents a modification in the traditional approach to teaching courses in materials and manufacturing processes. The argument is made that a comprehensive strategy of integrating the materials and manufacturing course sequences in B.S. degree programs in MET and MFET, such as those currently offered at Purdue University, has merit. Included is the development of a systems approach to teaching materials and processes, which is progressively more evident in the curriculum modifications as the student advances into upper-level courses.

There is some evidence of the integration of materials and manufacturing at other institutions, but in some cases it seems to be a result of the need to reduce credit hours rather than to improve the curriculum. One example, described by Griffin and Creasy [10] at Texas A&M reduced a materials course (4 hours) and a manufacturing course (3 hours) into one integrated course worth 4 credit hours. This course includes a laboratory component to support the lecture [13]. Other combined courses in recent literature include a materials, manufacturing and design laboratory course at University of South Alabama [12]. In this case however, the course is only a single credit hour for sophomore level students.

The study of manufacturing engineering has been the focus of several recent conferences and gatherings since, as Waldorf *et al* [11] says, "countless media headlines have convinced many prospective students that an education in manufacturing is a waste of time". Waldorf continues, "a need clearly exists to evolve the curricula for manufacturing engineers and to reevaluate current educational strategies". Purdue has a Manufacturing Engineering Technology program, but that doesn't relieve the Mechanical Engineering Technology program of the need to expose its students to manufacturing processes and concepts.

Waldorf *et al* [11] found a need to teach global issues in manufacturing, use project based activities with real world constraints, and improve student's communication skills. This included going beyond the recommendations of ABET to teach "globalization, sustainability and lean manufacturing issues" [11]. This need must obviously be balanced by available resources for, as Liou [15] points out; it is "unrealistic to expect that every institution will be equipped to handle a broad range of "real-life" products used for product realization projects".

Other institutions have recognized the need for a course in manufacturing processes. Recently, Farrow [14] writes of the University of Tennessee at Martin adding an upper division course in manufacturing for its mechanical and industrial students. But this course is an elective that is taken after a separate required course materials.

Liou [15] also writes, "manufacturing is more than machining . . . the manufacturing industry needs to be seen holistically – as a complete system involving many people of varying educational backgrounds".

Development of this new integrated materials and manufacturing approach included work by Purdue faculty at West Lafayette (main campus), and three of the five Statewide Technology locations (New Albany, South Bend, and Columbus) that serve Purdue students throughout Indiana.. Table 1 shows some statistical data about the various Purdue locations.

	Purdue	**PSI**	**PSB**	**PUC**
Location	West Lafayette, IN	New Albany, IN	South Bend, IN	Columbus, IN
MET Students	400	70	36	49
MET Faculty	19	3	1	2
Adjunct Faculty	0	0	4	1-2

Table 1. Mechanical Engineering Technology Statistic for various Purdue locations.

Even with the Mechanical Engineering Technology students and faculty spread across the state of Indiana, course uniformity is maintained through the use of Core Learning Objectives (CLOs). In this system, every course has a list of objectives that have been approved by the MET Curriculum Subcommittee. These course objectives list the critical skills that the students need to have upon the completion of the class. Having a CLO for each class ideally ensures that every student finishes a class with the same general skill set regardless of location or instructor.

The CLOs are created and revised through a formal process. First, faculty members involved in a course propose new or revised CLOs to the curriculum Area Committee responsible for the course. Area Committees are comprised of faculty that teach a particular subject in the Mechanical Engineering Technology curriculum. The Area Committee then reviews the proposed CLOs or revisions. The committee may choose to recommend approval as proposed, edit and then recommend approval, send the CLO back to the initiator for further work, or reject the CLO as not appropriate for universal adoption. If approved, the Area Committee Chair brings the proposed CLOs to the MET Curriculum Subcommittee for consideration. If approved by the MET Curriculum Subcommittee, the CLOs are distributed to all MET faculty for their adoption and use.

II. EXISTING COURSE SEQUENCE & CONTENT

Until recently, the Mechanical Engineering Technology department had required undergraduate students to take one materials class and two manufacturing processes classes. These classes are described below.

Materials I (MET 141)

Materials I covers the four traditional groups of engineering materials: metals, polymers, ceramics and composites. Materials I is usually taken the first semester of freshman year. It begins with a review of chemistry and then an introduction to material and mechanical properties. Students learn about hardness, tensile and yield strength, impact strength, brittle and ductile failures, phase diagrams and other concepts relating to material properties. After spending a couple of weeks on general material concepts, the remaining semester is divided into the study of the specific properties of each of the four traditional material groups. The study of metals includes a significant amount of time devoted to ferrous alloys and then an examination of nonferrous alloys such as aluminum, copper, titanium and etc. The polymer segment addresses the polymerization of monomers and the concepts of chain length, networking and cross-linking as well as a discussion of common types of polymers. One or two classes are devoted to ceramics and several classes cover composite materials. The discussion includes how fibers and matrices are combined to form composites and why composites are used. Table 1 in Appendix 1 lists the Core Learning Objectives for MET 141.

The Materials I laboratory exercises start with a simple lab entitled “Basic Measurements and Material Properties”. This lab serves to orient the student in the tools and equipment used for the remaining labs. Next the students measure some material properties with a hardness lab and a tensile-test lab. During the study of metals, students perform a phase diagram lab, two heat treatment labs (steel and aluminum) and prepare and examine a metallographic specimen. Lastly they complete a lab that examines the identification of polymers. The labs for Materials I are mostly “cookbook” type exercises with little opportunity for students to really experiment. In addition, depending on the instructor, the labs may not always be synchronized with the lectures.

Manufacturing Processes I (MET 142)

Manufacturing Processes I exposes students to the fundamentals of casting, forming, and joining processes using a traditional format of classroom lecture and observational or partial-participation lab exercises. The course is usually taken the second semester of a student’s freshman year.

In the lecture portion of the class the semester is divided into three segments. The first segment (approximately 45% of the total lecture content) introduces casting processes, beginning with the fundamentals of single-use molds (sand casting, investment casting, etc) and continuing through multi-use molds and patterns to polymer molding operations. The second segment (40%) covers the basics of forming operations, relying on material temperature to distinguish the hot and cold processes of forging, extrusion, drawing, bending and shearing. Finally, the last segment (15%) presents joining fundamentals and concentrates on welding and soldering operations. Table 2 in Appendix 1 lists the Core Learning Objectives for MET 142.

Labs provide broad but shallow exposure to common casting, molding and joining processes. These have sometimes limited student participation since a technician operates most of the equipment. The casting segment includes green sand casting, CO_2 process, lost foam, and investment casting operations. The molding segment includes rotational, injection, expanded bead, compression, vacuum, chemical foam, and hot dip molding operations. In the joining segment, students weld pieces of steel (SMAW process) and solder copper pipe fittings.

Manufacturing Processes II (MET 242)

Manufacturing Processes II is taken concurrently with Manufacturing Processes I during the freshman year. It is often referred to as the "cutting class" due to its heavy emphasis on machining operations and tools. Exploration of traditional machining topics dominates both the lecture and lab components, and includes cutters, turning, drilling, threading, milling, broaching, sawing, filing, and abrasive processes. The basics of measurement tools, numerical control, and non-traditional machining processes are also presented. Table 3 in Appendix 1 lists the Core Learning Objectives for MET 242.

The primary lab exercise consists of manually manufacturing a 2-piece steel hammer using milling, turning, and lathe operations over an eight week period that at times resembles an introductory machinists approach. Single-class labs on measurement and CNC programming are also included.

A Need for Change

As stated above, the traditional approach at Purdue to teaching courses in materials and manufacturing processes as separate concepts had weaknesses. The primary weakness was that the content was presented as discrete topics with minimal linkage to overall process functionality and the awareness of the potential for optimization. Since many material properties are intrinsically tied to the manufacturing processes, it was difficult to teach materials without discussing manufacturing processes and vice versa. Thus the materials course had to devote time to the discussion of the effects of manufacturing on material properties and the manufacturing courses reviewed the key concepts of materials science while explaining manufacturing processes.

In addition, the faculty had identified the lack of several important but neglected topics in the materials/ manufacturing sequence. These included: the encroachment of process variability and its effects on product quality, statistical quality control concepts, especially as they relate to product/process measurement, and an introduction to process automation and integration. All of these issues lead to a proposal to extensively revise the materials and manufacturing courses.

III. COURSE MODIFICATION PROCESS

Revision of the materials and manufacturing courses was subject to two main constraints. First, the revised courses had to stay with 12 credit hours currently required so as to not affect the total number of credit hours required for a MET degree. Secondly, the revisions had to address the weaknesses previously identified by the faculty and integrate the instruction of materials and manufacturing processes.

First, interested faculty pooled all current and proposed course content to create a list of potential content for three courses consisting of a total of 12 hours of credit. This lead to several group discussions to decide which topics belonged in each class, and how the classes should be structured and tied together in order to create greater continuity in the courses. This created an overall map for how each course fits the strategy of an more integrated materials and manufacturing curriculum.

Next, the courses were divided among committee members so each person could focus on a specific topic and develop appropriate CLOs and content for the individual courses, while knowing how its pieces fit the overall course continuity plan. The CLOs and content were reported back to the committee chair to summarize the individual efforts and then a group discussion resolved any lingering questions.

Lastly, the committee chair presented the results to the Curriculum Committee for their input and approval. Once Curriculum Committee approval was secured, limited testing of the curriculum changes was implemented in the 2007/2008 school year, with full rollout of the new courses scheduled for the 2008/2009 school year.

IV. NEW INTEGRATED COURSE SEQUENCE

The new courses that integrate materials and manufacturing for the new curriculum are described below. The courses were given new course numbers due to the fact that content represents a revolutionary and not an evolutionary change to the course topics.

Materials & Processes I (MET 143)

Materials & Processes I will be a Materials and Manufacturing Processes course dealing with structure, properties and processes of metals and ceramics. Approximately ¾ of the course will deal with the study of metals and related processes, while the remaining ¼ covers ceramics. MET 143 will be scheduled for the first semester of the student's freshman year. Since this is the first materials and processes course, as well as likely the first MET course a student will take, additional time will be spent at the beginning of the semester on generalized material properties and other introductory concepts.

The course will then begin the study of metals and metal manufacturing processes. Since the course is now integrated, at the same time metal properties (i.e. tensile strength) are presented, a significant amount of class time can also be devoted to a discussion of their relevant manufacturing processes (i.e. heat treating, cold forming, hot rolling, forging, etc.) and how these can affect a metal's properties. With labs and in-class exercises, students will learn to predict the results of the different manufacturing processes. Students will learn about casting metals, the difference between single-use and multi-use mold processes and cast aluminum, zinc or tin in laboratory exercises.

After this foundation of metal types and properties is learned, the course will move to a discussion of secondary processes commonly performed on metals. This includes the basic material removal processes (turning, boring, milling, etc), as well as forming (drawing, bending, etc) processes. Students will also learn the techniques and advantages and disadvantages of joining processes including common fusion and solid-state welding processes and integral, discrete, and shrink/expansion fastener systems. Students will apply these concepts in order to select and apply appropriate secondary processes that can effectively execute a given manufacturing task, potentially in the form of a comprehensive laboratory project that incorporates numerous aspects of the course.

Powder metallurgy manufacturing processes will conclude the discussion of metals and provide a transition to the introduction of ceramic materials. Just as with metals, students will learn the types and properties of ceramics and the common fabrication processes for amorphous and crystalline ceramics.

Late in the semester, students will present their own research on metal/ceramic materials or processes orally and visually. This exercise replaces the practice in the existing materials course of presenting a lab exercise that tended to be tedious and uninspiring. Instead students will be encouraged to create a presentation related to a sport, hobby, job or other activity in which they have an interest. Successfully completing the presentation will show that the students can communicate with colleagues in their field using common terms of foundry, joining, powder metallurgy, hot/cold working, and the ceramic fabrication industries. Table 4 in Appendix 2 lists the Core Learning Objectives for MET 143.

<u>Materials & Processes II - MET 144</u>

Materials & Processes II will be similar in format to Materials and Processes I except it will cover polymers, composites and other advanced materials. A big change from the existing courses is that significantly more time will be devoted to polymers, composites and advanced materials. In this class students will identify major traditional polymers and alternative materials used in the production of consumer products. They will learn about polymeric material properties and the major molding, forming, shaping and joining processes used in the manufacture of polymeric products. In addition, the class will add lessons on the concepts of sustainability and product life cycle management with regards to polymers and alternative materials and processes.

After spending about two thirds of the class on polymers, the focus will shift to discussion the materials and fabrication techniques used to produce particulate, laminar, and fiber-reinforced composites. Since the students should have already taken the class on metals and ceramics, the discussion of composites will also include composites made of metallic or ceramic materials. The remainder of the semester will cover biomaterials and biomedical device manufacturing concepts, green materials and manufacturing strategies and the key differences between traditional manufacturing and advanced industries such as pharmaceutical and biomedical manufacturers.

Lastly, students will learn to perform objective quality inspection, analyze basic material and manufacturing-related defects, and recommend appropriate modification that would be likely to reduce or eliminate the defects and/or provide for more efficient design and manufacturing. Table 5 in Appendix 2 lists the Core Learning Objectives for MET 144.

Manufacturing Systems - MET 245

Manufacturing Systems will cover the myriad of manufacturing processes but within a generalist, systems framework by integrating lecture topics and lab exercises. This class begins with integration of fundamental material removal operations with CNC operations in order to design and produce a multi-component prototype product. Project management tools will be used to introduce students to concepts of the flow of material and product components through unit operations, engineering tasks and inputs, and labor required to design and develop new products such as the prototype assigned. During the course of this 3 week lab, lecture material on basic cutting operations and important parameters, process optimization, and product design for manufacturability are introduced.

Next the topics of measurement tools and methods, and statistical quality control are introduced in a manner that shows their interdependence and impact on production of high quality products at high volume rates. The emphasis during this segment is on the techniques and importance of measuring product features at various process points and linking their impact to both final product quality and process capability.

At this point, students are reintroduced to processes and their important parameters using specific process diagramming tools such as Process Flow Diagramming (PFDs) to document a wide range of processes and products. Visualization of the interaction of the flow of materials with the important process variables required to make products is emphasized. Videos of actual manufacturing processes from universities like Stanford[9] and shows such as “How It’s Made” provide exposure to a large quantity of relevant information on manufacturing in this country.

The final few weeks of the class introduce students to increasing sophistication of manufacturing including the job-shop, flow shop, and work cell approaches to mass production. This is combined with fundamentals of process optimization that explore materials, manpower, and process layout in the form of integrated lab exercises. These exercises use LEGO cars to demonstrate the relative advantages, disadvantages, and design aspects of the manufacturing approaches mentioned above. Student teams ultimately compete against each other in categories such as highest output, most efficient labor, and highest quality production as they develop increasingly sophisticated models of mass production operations. Table 6 in Appendix 2 lists the Core Learning Objectives for MET 245.

V. CURRENT STATUS

Rollout of the above courses is progressing along a two year plan. By the end of the 2006-2007 academic year all core learning objectives for all courses had been approved by the Curriculum Committee. In the current academic year (2007-2008), New Albany has taken the lead in applying selected aspects of the new approach to all courses. In particular, MET 242 course content has been substantially modified to incorporate "systems" concepts. Substantially less emphasis is being placed on the machinist's approach to cutting operations, in favor of an approach linking process and manufacturing engineering aspects to unit operations and their optimization. During the 2008-2009 academic year any remaining aspects of the new approach will be incorporated, and all new course numbers, contents, and laboratory exercises will be implemented.

Even with the curriculum changes described above not completely implemented, additional course changes have already been proposed to continue the integration of materials and manufacturing topics. First, a follow-up elective for Manufacturing Processes – MET 245 may be developed that continues the study of manufacturing at an advanced level for upper division students. In addition, Materials II - MET 344 (an existing course) will possibly be changed to a course titled "Advanced Materials in Manufacturing". This course currently spends most of the semester covering metals and then studies polymers late in the semester. This course many be changed to cover advanced materials and processes more relevant to modern industrial practices.

The integration of the teaching of materials and manufacturing described above was a result of the MET Faculty's strong recognition of the need to improve the existing organization and emphasis of the materials and manufacturing courses. Despite the amount of work required to make such a large scale curriculum change across several locations, the materials and manufacturing courses in the Mechanical Engineering Technology department were successfully integrated to improve student learning.

VI. ASSESSMENT

As stated above, the New Albany location is furthest along in the curriculum changes, and thus also has begun the assessment planning process. The assessment of the new materials and manufacturing courses will be similar to the current assessment of existing courses that support the Program Objectives of the MET program. Program Objectives are five overarching goals of the MET program that correlate to the criteria for accreditation by ABET. In a general sense, assessment of the courses begins with the collection and retention of specifically identified assessment tools for evaluation at the end of the first school year that the new courses are offered. For the most part, the assessment tools for a specific class are assignments, reports and tests that relate to a specific Core Learning Objective (CLO) for the course. These relevant assignments are identified by the course instructor and their metrics and success thresholds discussed with all faculty. Each faculty member responsible for a particular assignment then evaluates it and determines whether or not the criteria for success are met.

An example of a CLO for a materials course is: "Use a σ-ε diagram to determine yield strength, tensile strength, percent elongation, modulus of elasticity, modulus of resilience, and modulus of toughness and describe how these properties predict material behavior." The specific assessment mechanism is a question on the final exam where the students must use a σ-ε (stress-strain) diagram to determine the material properties described in the CLO and then write a paragraph describing how these properties predict material behavior. Solutions are graded to indicate the accuracy of the student's determination of the material properties as well as their justification of their answer. The evaluation metric for this assessment point is the class average of individual student grades and the standard for success is that 75% of the students supply the correct answer. Other assessment tools include analyzing lab reports, oral presentations and group work.

After all assessment points are evaluated individually, the faculty reconvenes and discusses each point. The faculty as a whole then decides; a) what corrective actions would be taken for any assessment point that did not meet its threshold of success, b) how all assessment points and methods might be improved in the subsequent year, and c) ways the overall assessment and evaluation process could be strategically improved over coming years.

VII. CONCLUSIONS

Faculty at Purdue University decided to integrate the teaching of materials and manufacturing processes in order to enhance student learning. Review of current literature found a few instances of the combination of materials and manufacturing but for the purpose of curriculum management, not to enhance student learning. However, a call for a holistic approach to materials and manufacturing by ABET and others was identified. Following course modification procedures, MET Faculty extensively revised the materials and manufacturing courses required for a MET degree. The new courses will be implemented in the 2008-2009 school year and detailed assessment of them will follow.

VI. REFERENCES

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VII. APPENDIX 1 – EXISTING COURSE OBJECTIVES

TABLE 1. MATERIALS I - MET 141 COURSE OBJECTIVES	
After completing this course, the student should be able to:	
1.	Use and properly read various hand held micrometers and calipers.
2.	Test material hardness using Rockwell, Brinell, and various portable testers and convert between Rockwell and Brinell hardnesses and estimate tensile strength from Rockwell and Brinell hardnesses.
3.	Use a σ-ε diagram to determine yield strength, tensile strength, percent elongation, modulus of elasticity, modulus of resilience, and modulus of toughness and describe how these properties predict material behavior.
4.	Use phase diagrams to determine what phase are present, their compositions and amounts, and predict the results of heat treating metal alloys.
5.	Explain compositional and property differences between a ferrous and nonferrous metal.
6.	Describe how polymers are made from mers and how polymer characteristics are affected through chain lengths, networking, and cross-linking.
7.	Identify brittle and ductile failure types and describe the effect of temperature and surface defects on impact toughness.
8.	Describe how fibers and matrices are combined to form composites and explain why composites are used.
9.	Work in teams to organize a lab exercise into a review and present the review as an oral and visual presentation.
10.	Mount, grind, polish and etch a metallographic specimen and identify features of the specimen's microstructure.

TABLE 2. MANUFACTURING PROCESSES I - MET 142 COURSE OBJECTIVES	
After completing this course, the student should be able to:	
1.	Communicate with colleagues in their field using common terms of foundry, joining, powder metallurgy, hot working, and polymer/ceramic/composite fabrication industries
2.	Describe key process variables when working with molten metal.
3.	Describe key design considerations for gating systems, risering, patterns, and molds.
4.	Identify and differentiate between common single-use and multi-use mold processes by describing processes and listing advantages and disadvantages of each process.
5.	Describe a typical powder metallurgy manufacturing process and explain its advantages and disadvantages.
6.	Explain how hot working differs from cold working.
7.	Describe and differentiate between the hot working processes of rolling, forging, and extrusion.
8.	Describe the common fabrication processes for thermoplastic and thermoset polymers.
9.	Describe the common fabrication processes for amorphous and crystalline ceramics.
10.	Describe the fabrication techniques used to produce particulate, laminar, and fiber-reinforced composites.
11.	Describe the common fusion and solid-state welding processes.
12.	Describe materials used for adhesive bonding and their advantages and disadvantages.
13.	Differentiate between integral, discrete, and shrink/expansion fastener systems and list advantages and disadvantages of mechanical fasteners.
14.	Make basic recommendations related to product design that would allow more efficient manufacturing.
15.	Perform objective quality inspection, analyze basic manufacturing-related defects, and recommend appropriate modification that would be likely to reduce or eliminate the defects.

TABLE 3. MANUFACTURING PROCESSES II - MET 242 COURSE OBJECTIVES	
After completing this course, the student should be able to:	
1.	Use common process documentation in the design of a manufacturing process.
2.	Identify the basic material removal processes: turning, boring, drilling, reaming, milling, sawing, broaching, shaping, and grinding.
3.	Use measuring instruments correctly to obtain accurate readings of workpiece dimensions.
4.	Specify an appropriate measuring system that complies with the precision of a blueprint specification given the measuring environment in which the operation is to be performed.
5.	Determine the basic material removal processes that can effectively execute a given manufacturing task.
6.	Identify a suitable machine tool for a specific material removal situation.
7.	Select an appropriate cutting tool type, material and rake angle for a specific material removal situation given the blueprint specifications (workpiece geometry, material, tolerances and surface finishes), the manufacturing operation to be performed, the machine tool to be used, and the desired level of productivity.
8.	Obtain recommended speeds and feeds from reference tables.
9.	Calculate speed, feed, and depth of cut for material removal operations.
10.	Use an indicator to establish precise location; set speed, feed, and depth of cut; and execute turning and milling operations on manually operated machine tools.
11.	Determine the relative productivity of turning, drilling and milling operations by calculating cut times and material removal rates.
12.	Estimate the power required of the machine tool motor for turning, drilling and milling operations.
13.	Identify the common mechanical, thermal, chemical and electro-chemical non-traditional machining processes given a description and picture of the operation.
14.	Write, simulate, and debug a numerical control program for a 2 1/2 axis milling machine.
15.	Determine the basic cold forming processes that can effectively execute a given manufacturing task.
16.	Use basic manufacturing terminology fluently in communication with manufacturing personnel in a precision manufacturing environment.
17.	Participate in a team to execute a manufacturing project and accurately document the results in a professional-quality report.

VIII. APPENDIX 2 – NEW INTEGRATED COURSE OBJECTIVES

TABLE 4. MATERIALS AND PROCESSES I - MET 143 COURSE OBJECTIVES	
After completing this course, the student should be able to:	
1.	Use phase diagrams and metallographic specimens to explain the compositional and property differences between alloys of ferrous and non-ferrous metals, including determining what phases are present, their compositions and amounts.
2.	Use stress-strain diagrams to determine material properties of both ferrous and non-ferrous metals.
3.	Conduct material property tests using standard methods and instrumentation.
4.	Identify brittle and ductile failure types and describe the effect of temperature and surface defects on impact toughness.
5.	Communicate with colleagues in their field using common terms of foundry, joining, powder metallurgy, hot/cold working, and the ceramic fabrication industries.
6.	Describe key process variables when working with molten metal.
7.	Identify and differentiate between common single-use and multi-use mold processes by describing processes and listing advantages and disadvantages of each process.
8.	Describe the common fabrication processes for amorphous and crystalline ceramics.
9.	Describe a typical powder metallurgy manufacturing process and explain its advantages and disadvantages.
10.	Identify the basic material removal processes: turning, boring, drilling, reaming, milling, sawing, broaching, shaping, and grinding and determine the material removal processes that can effectively execute a given manufacturing task.
11.	Determine the basic cold forming processes that can effectively execute a given manufacturing task.
12.	Describe and differentiate between the hot working processes of rolling, forging, and extrusion and predict the results of heat treating metal alloys.
13.	List advantages and disadvantages of joining processes including common fusion and solid-state welding processes and integral, discrete, and shrink/expansion fastener systems.
14.	Present data on metal/ceramic materials or processes orally and visually.

TABLE 5.
MATERIALS AND PROCESSES II - MET 144
COURSE OBJECTIVES

After completing this course, the student should be able to:	
1.	Differentiate between the structure and characteristics of the major thermoplastic and thermoset polymers.
2.	Understand the terminology pertaining to industries involving polymers or alternative materials.
3.	Identify major traditional polymers and alternative materials used in the production of consumer products.
4.	Conduct material property tests using standard methods and instrumentation.
5.	Research polymeric materials and processes using various resources.
6.	Describe key design considerations for gating systems, molds and other process equipment components.
7.	Identify and describe the major molding, forming, shaping and joining processes used in the manufacture of polymeric products.
8.	Display safe and environmentally sound methods of working with polymeric materials and processes.
9.	Understand the concepts of sustainability and product life cycle management with regards to polymers and alternative materials and processes.
10.	Describe how fibers and matrices are combined to form composites and explain why composites are used.
11.	Describe the fabrication techniques used to produce particulate, laminar, and fiber-reinforced composites.
12.	Describe biomaterials and biomedical device manufacturing concepts.
13.	Identify green materials and green manufacturing strategies.
14.	Describe the key difference between traditional manufacturing and industries such as pharmaceutical and biomedical device.
15.	Perform objective quality inspection, analyze basic material and manufacturing-related defects, and recommend appropriate modification that would be likely to reduce or eliminate the defects and/or provide for more efficient design and manufacturing.

TABLE 6. MET 245 MANUFACTURING SYSTEMS COURSE OBJECTIVES	
After completing this course, the student should be able to:	
1.	Use common process documentation tools and techniques in the design of a manufacturing process, including process flow diagrams and process data charts.
2.	Identify the important parameters associated with basic material removal processes: turning, boring, drilling, reaming, milling, sawing, broaching, shaping, and grinding, and their interrelationships.
3.	Use instruments and techniques for the measurement and inspection of product and process attributes, including measuring instruments, the "Rule of 10", standardizing and referencing techniques (gage blocks), and non-destructive testing (NDT) methods.
4.	Specify an appropriate measuring system that complies with the precision of a blueprint specification given the measuring environment in which the operation is to be performed.
5.	Select an appropriate cutting tool type, material and rake angle for a specific material removal situation given the blueprint specifications (workpiece geometry, material, tolerances and surface finishes), the manufacturing operation to be performed, the machine tool to be used, and the desired level of productivity.
6.	Understand and use relationships involving cutting operations; including obtaining recommended speeds and feeds from reference tables, calculation of feed/speed/depth relationships, and optimization of material removal rate (mrr) versus power and cycle time.
7.	Identify the common mechanical, thermal, chemical and electro-chemical non-traditional machining processes and their important operational parameters.
8.	Write, simulate, debug, and use a CNC program for a 2 1/2 axis milling machine to produce an assigned component.
9.	Participate in a team to optimize a manufacturing process and accurately document the results in a professional-quality report and oral presentation.
10.	Use fundamental Statistical Quality Control tools to construct X-bar & R-bar Control charts and identify special/common cause defects from measured production parts.
11.	Determine the assembly/joining process that can effectively execute a given manufacturing assignment, including methodologies for optimization of aspects such as throughput, reject rate, and labor/material costs.