AC 2012-3113: AN EXAMPLE MAPPING OF THE FOUR PILLARS OF MANUFACTURING ENGINEERING ONTO AN EXISTING ACCREDITED PROGRAM

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David L. Wells has been professor of industrial and manufacturing engineering at North Dakota State University since January 2000. He teaches undergraduate and graduate courses in process engineering and production engineering systems design for conventional manufacturing, electronics assembly, biomedical products, and micro-manufacturing. His instruction is characterized by heavy reliance upon project-based, design-centric learning. Course projects are drawn from real industrial applications with real industrial constraints, often interactive with a corporate sponsor. Students are challenged to design effective and efficient part manufacturing methods and complete production systems for commercial and industrial products. The common theme for students is mastering process and system design procedures that are applicable to any product in any industry. Graduates have been successful in manufacturing enterprises that produce virtually every type of product, literally, from spacecraft to foodstuffs. Wells also leads innovation teams in two engineering venues: product realization and transforming laboratory research into commercial products. Wells' active research lies in orthopedics, micro-assembly, micro-machining, circuit board process engineering, printed electronics, applications of RFID technologies, and manufacturing engineering pedagogy. Through his research, Wells has supervised the completion of twelve graduate degrees in the past seven years. His publication history includes nearly seventy print publications and over forty invited presentations. He has addressed professional audiences in Ukraine, Japan, India, Brazil, Peru, Mexico, and Canada, as well as in many United States venues. For many years, he has been active in the national leadership of Society of Manufacturing Engineers, American Society for Engineering Education, and ABET. Over the past 28 years, he has been a central figure in the design, development, and articulation of curricula for educating manufacturing engineers in the United States and in selected off-shore venues. He has also been an occasional contributor to Surface Mount Technology Association and Institute of Electrical and Electronics Engineers. Prior to joining NDSU, Wells held manufacturing engineering and management positions in energy, aerospace, commercial sheet metal, and automotive industries for 26 years. He also held a faculty position at University of Cincinnati for 15 years, including 13 years as Chair of a department of some 500 students. He has also served as an Academic Dean in an experimental Manufacturing Engineering Education program at Focus: HOPE (Detroit, Mich.) and as Chair of the IME Department at NDSU. Wells is a certified Manufacturing Engineer and earned a B.S. and M.S. in mechanical engineering from Stanford University, and a Ph.D. in engineering management from the Missouri University of Science and Technology.

An Example Mapping of the Four Pillars of Manufacturing Engineering onto an Existing Accredited Program

Abstract: The four pillars of Manufacturing Engineering have been devised to provide direction to undergraduate curricula. The headings of the pillars are taken from the ABET program criteria for "Manufacturing and Similarly Named Engineering Programs". The fifth program criterion requires that instruction include laboratory exercises with substantive intellectual content. This paper will map the four-plus-one pillars construct onto an existing accredited program in Manufacturing Engineering. The results of this comparison will be used as part of the documentation offered for a forthcoming re-accreditation evaluation. The overlay of the four pillars highlights some needed improvements, and directions for implementation of those refinements are discussed. The method applied here suggests more general application for identifying areas of needed continuous improvement in undergraduate Manufacturing Engineering and Manufacturing Engineering Technology programs.

Historical Foundation: Manufacturing Engineering at North Dakota State University is offered within a combined Industrial and Manufacturing Engineering Department, co-existing side-by-side with a sister program in Industrial Engineering and Management. The Manufacturing Engineering program at NDSU was first separately accredited in 2000. In that same year, graduate study in the discipline was inaugurated, and separate BS and MS degrees are offered in both Manufacturing Engineering and Industrial Engineering and Management, with the doctorate being in the combined disciplines -- Industrial and Manufacturing Engineering.

Program Philosophy: From the start, NDSU Manufacturing Engineering has been focused on the production of products, articulated in the mantra that … at the end of the day, manufacturing is about production of goods. Manufacturing engineers are called upon to make decisions about technology, machines, people and money -- all related to the production of tangible goods. The primary responsibility of the manufacturing engineer is to assure that the products are created with the functionality intended by their designers and at a level of quality that will satisfy and delight customers. Close on the heels of that primary responsibility comes focused concern for time and money. In order to be successful -- indeed, to remain in business, manufacturing enterprises must get new products to the marketplace quickly and must produce goods at costs that permit adequate profit while satisfying customers' needs for value purchasing.

Manufacturing Engineering is a bottom-up discipline, based upon a strong foundation of science and mathematics. The linchpin is comprehensive understanding of the science of the interactions between tool and workpiece. The production system of the factory is built on this foundation, with all design and operating decisions emanating from fundamental principles of the physics and chemistry (and more recently, the biology) of materials processing. Manufacturing Engineering is also a design profession, where practitioners are required to make decisions to create processing plans and production systems based on both fundamental analysis and the often-conflicting exigencies of the imperative to produce goods -- at needed quality and functionality and with timely and cost-effective delivery to the customer.

Establishing and Refining Program Objectives: Based upon this mantra, program objectives have been established for the undergraduate NDSU Manufacturing Engineering program. Initially, the program learning objectives were defined within the structure determined by repeated examinations in workshops, conferences and forums sponsored by the Society of Manufacturing Engineers over the two decades preceding the founding of the NDSU Manufacturing Engineering program.[a] This structure has been reported extensively, and has been summarized into six core knowledge stems:

product design
engineering materials
manufacturing processes
production systems
automations & controls
manufacturing/quality management

Figure 1: The Six Core Knowledge Stems in Manufacturing Engineering[1]

Decisions were made quite early in the program's history that instruction should be integrated -- i.e., that separate courses ought not to be offered for separate elements of the core knowledge stems, but that fundamental concepts should be integrated throughout the curriculum. This attitude led directly to an orientation towards a concentration on relevant aspects of engineering -- i.e., based on the fundamental characteristics of engineers as problem-solvers and designers of products and processes. The result was a focus on four basic aspects of manufacturing engineering … product engineering; process engineering; quality engineering; production engineering.[2] This was quickly compressed by integrating quality issues within the engineering of products, processes and production systems.[1]

In addition, laboratory experiences were adopted as a central feature of all coursework in the Manufacturing Engineering major. The standard course format is three-credits, which includes two lecture hours and three laboratory hours per week. There are occasional variations to more or less laboratory content in certain of the elective courses. A Manufacturing Engineering capstone has evolved that is centered around the broad concept of 'product realization', taking senior students through a comprehensive experience that encompasses all of the knowledge stems for the discipline and touches each of the program accreditation criteria.

As the NDSU Manufacturing Engineering program matured through its first re-accreditation evaluation, the curricular threads woven through the core courses, the six core knowledge stems and the accreditation program criteria became more thoroughly integrated. ABET program

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[a] The principal events were: Workshop on Minimum Content for Manufacturing Education Programs, Heuston Woods, July 1985; Curricula 2000 Workshop, Southfield, July 1990; Curricula 2002 Workshop, Orlando, March 1995.

criteria for ‘manufacturing and similarly named engineering programs’ have been conceptually stable for about two decades -- materials and manufacturing processes; product, process and assembly engineering; manufacturing systems and operations; manufacturing competitiveness; laboratory experience.[3]

The curricular threads have become defined as the core competencies of a Manufacturing Engineer from North Dakota State University -- product engineering; process engineering; production engineering.[1] In this visage, ‘product engineering’ encompasses detailed analysis of the product and all component parts, as well as an assessment of customer demand in both qualitative and quantitative terms. Quality requirements stem from identification and analysis of those characteristics of component parts that [a] are necessary for acceptable functionality of the completed product and [b] are measurable during manufacturing. ‘Product engineering’ also includes make-versus-buy decision-making, detailed specification of dimensional requirements for all manufactured parts (including fits, tolerances and surface finish) and explicit specification of raw materials (e.g., for metals, alloy, condition and mill form).

‘Process engineering’ includes the traditional manufacturing engineering activities of tool specification, fixture selection or design, machine tool specification and selection, process planning and machine-tool-level performance prediction (cycle time, tool consumption, raw material utilization). Particular emphasis is placed on [a] analytical modeling of the applicable manufacturing process(es), starting from fundamental variables (e.g., for machining processes, cutting conditions) and [b] complete process mapping and operations planning.

‘Production engineering’ incorporates fundamental quality engineering analysis and the essentials of cost engineering. The focus of ‘production engineering’ is the design of a production system for serial manufacture of selected tangible goods -- and then, the estimation of performance of the designed production system in terms of throughput, inventories and operating costs. Also incorporated are basics of market analysis -- for estimating production demand. The interactions amongst these the perspectives, competencies, knowledge stems and program criteria have been diagrammed to illustrate the strategy for delivering curricular content in fulfillment of objectives and criteria.

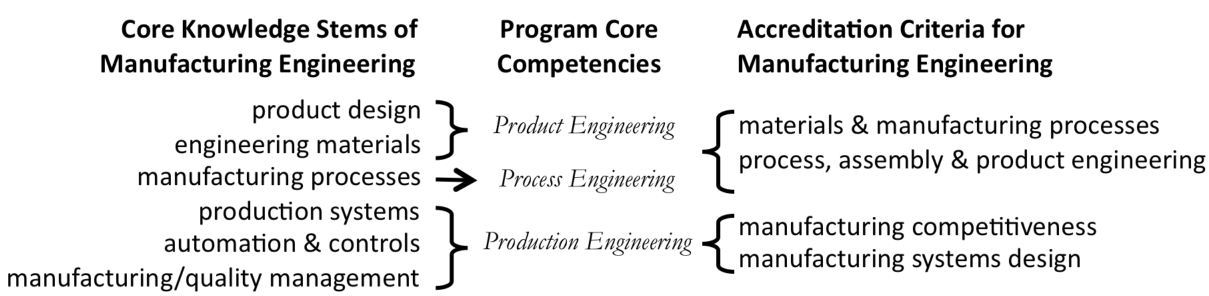

Figure 2: Correlation of Curricular Core Competencies, Core Knowledge Stems and Accreditation Program Criteria[1]

The program-wise learning objectives have recently been slightly re-cast into the format that is becoming known as the 'Four Pillars' of manufacturing engineering. This format evolved from the series of forums sponsored by the Society of Manufacturing Engineers from 2008 to 2010.[b] In addition to the event proceedings [4,5,6], the principal output of those forums was a comprehensive document defining a four-year plan for manufacturing education -- known as Curricula 2015.[7] The four-pillar concept emerged from that intensive effort, and it is a very useful tool for planning, describing and managing manufacturing curricula in both the engineering form and in engineering technology.

Program Description in 'Four Pillars' Terms: The Four Pillars have a foundation in the program accreditation criteria for Manufacturing Engineering.[8] As previously noted, these criteria have been in effect for ABET engineering accreditation for roughly two decades. During this time, the Manufacturing Engineering program criteria have been repeatedly reaffirmed through extensive dialogue amongst experienced faculty and critically-interested industrial practitioners -- most recently in 2011. In the most recent refinement, these criteria are[3] …

> Curriculum: The program must demonstrate that graduates have proficiency, using statistical and/or calculus-based methods, in
> [a] materials and manufacturing processes: *understanding the behavior and properties of materials as they are altered and influenced by processing in manufacturing*;
> [b] process, assembly and product engineering: *understanding the design of products and the equipment, tooling and environment necessary for their manufacture*;
> [c] manufacturing competitiveness: *understanding the creation of global competitive advantage through manufacturing and project planning, strategy and control*;
> [d] manufacturing system design: *understanding the analysis, synthesis and control of manufacturing operations, including simulation and information technology methods;*
> [e] laboratory experience: *measurement of manufacturing process variables in a manufacturing laboratory, manufacturing facility or realistic simulation and extraction of technical inferences about the process.*

The Four Pillars are visualized as the supports holding up the end objective of competitive manufacturing enterprises -- and in the process, describing the overall discipline of Manufacturing Engineering. These pillars are, thus, a structure that defines the content of post-secondary education in Manufacturing Engineering and Manufacturing Engineering Technology. The pillars are best grasped as a graphic representation of the edifice of the manufacturing sector.

The original conception of the Four Pillars also identifies an extensive selection instructional topics that further define each of the pillars.[8] As with all such topical specifications, there are far more highly relevant topics than can practically be accommodated as distinct courses in a time- and resource-limited undergraduate curriculum. The crucial topics must, therefore, be incorporated into a curriculum as modules integrated throughout the curriculum. Moreover, the extensiveness of the list of relevant topics becomes a powerful argument for creating an

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[b] The major events were: Manufacturing Education Leadership Forum, Pittsburgh, June 2008; 2nd Manufacturing Education Leadership Forum, Farmingdale, November 2008; Manufacturing Education Transformation Summit, Austin, June 2009.

educational program that emphasizes broad manufacturing concepts and universally-applicable principles, rather than industry-specific subject matter.

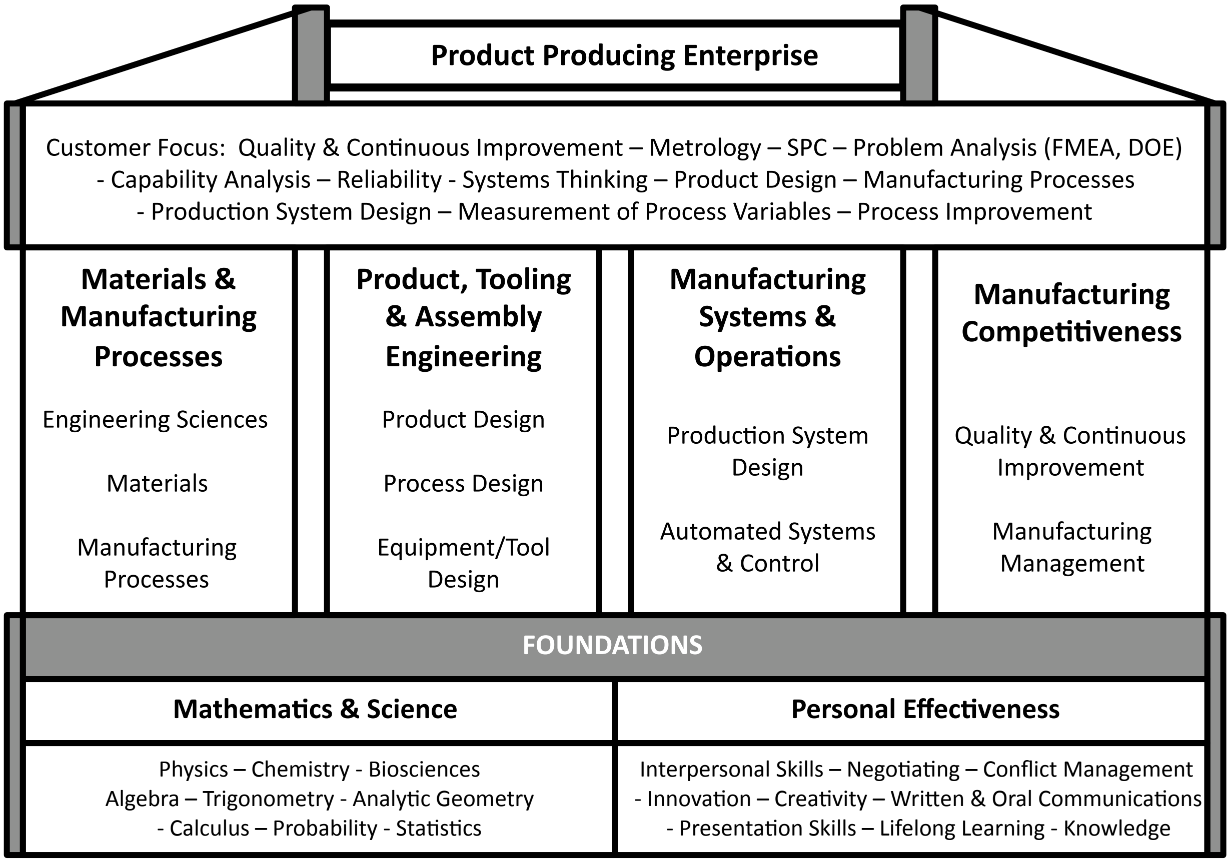

Figure 3: Visualization of the Four Pillars of Manufacturing Engineering, Represented as a Structure [adapted][8]

For the NDSU Manufacturing Engineering program, adapting to a Four Pillars model has been relatively straight-forward. The program has been pushing towards a universal-principles focus for some years, striving to integrate many crucial concepts throughout the program, rather than attempting to define new topic-specific courses. Examples can be found in the incorporation of modules and concepts of such crucial factors as quality, lean manufacturing, measurement of manufacturing parameters, market/customer assessment and process improvement. These topics are typically introduced in context throughout the concentration on the core competencies of product engineering, process engineering and production engineering.

A summary version of the Four Pillars edifice for Manufacturing Engineering at North Dakota State University is represented in Figure 4. In this model, the ultimate undergraduate objective is a 'product realization' capstone experience for students. This has been introduced in the past four years as an apt mimic for experiences that will quite likely be in store for graduates in our region. In the spirit of responding to the needs of our industrial constituency, the program faculty worked to build-in topical learning most relevant to the region.

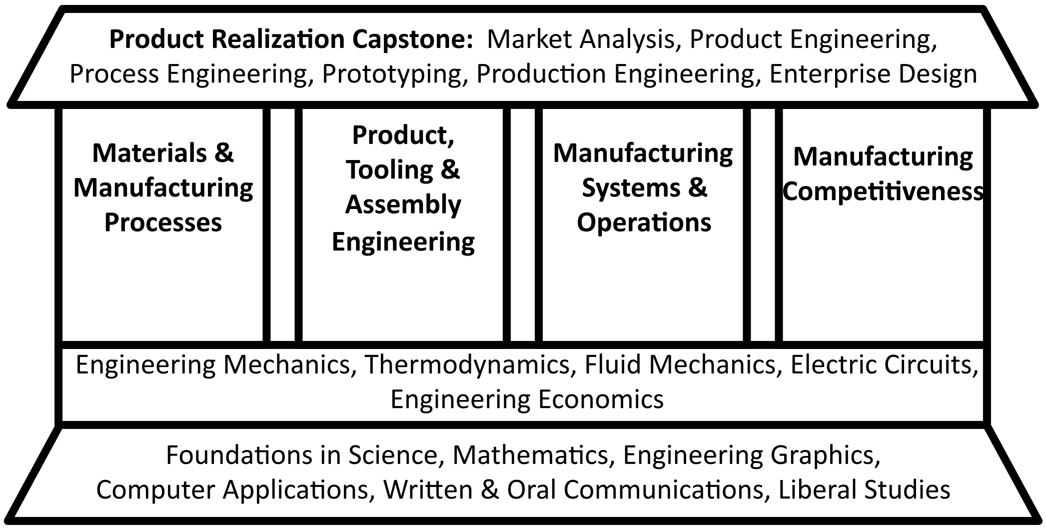

Figure 4: The Summary-form Edifice of Undergraduate Manufacturing Engineering at North Dakota State University

Firstly, over the past decade, the North Dakota manufacturing economy has been very strong, marked by increasing employment throughout most of the first decade of this century. The Fargo-Moorhead area and the Red River Valley Research Corridor have been particularly strong, adding to the manufacturing employment by 5.5 percent between 2001 and 2010.[9] Secondly, the economy of the North Plains region, and North Dakota in particular, is most heavily marked by smaller business enterprises. Large companies, such as dominate the scene in, say, southeastern Michigan, southern California and other traditional manufacturing centers, are rare in the North Plains. While traditional pillars of the regional manufacturing economy in recreational vehicles and agricultural and construction machinery remain highly competitive internationally, new companies abound. These new enterprises are concentrated in production of electronics, medical devices, pharmaceuticals and sustainable resource products. Moreover, agriculture (both basic and value-added) and energy extraction (coal and oil) remain as the largest economic sectors in the state.

Thus, the Manufacturing Engineering curriculum at NDSU is geared to provide skill sets applicable to small manufacturers, spread over a wide range of products and markets, but with a bias towards the industries of most importance to this region. The breadth of product and production technologies represented in the region leads to a strong curricular emphasis on widely applicable fundamental manufacturing engineering principles, while drawing project themes from regionally-important topics -- metal products, composites, electronics, medical devices, pharmaceuticals, food products, energy products.

The integration of highly-popular supporting topics can be illustrated by a modified four-pillar construct. This model emphasizes the integration of product and process quality, measurement of process variables, lean manufacturing concepts and methodology, and professional-caliber written and oral communications.

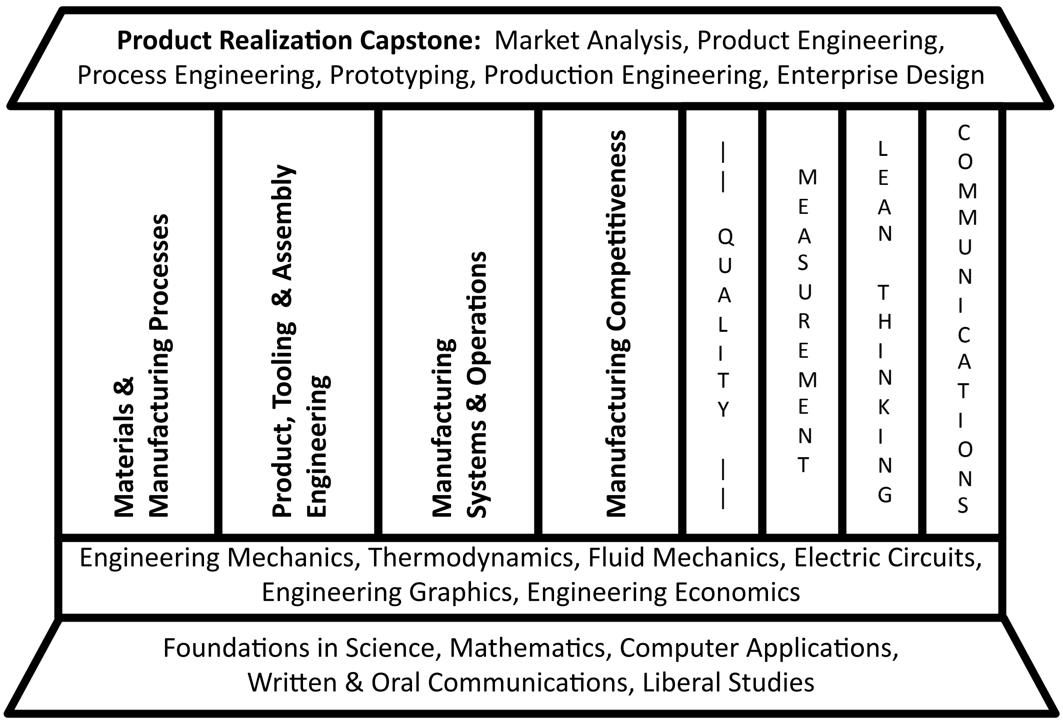

Figure 5: A Modified Summary-form Edifice for Undergraduate Manufacturing Engineering at North Dakota State University

Mapping of Course Content to the 'Four Pillars': The undergraduate Manufacturing Engineering program at NDSU is defined by nine required courses, plus the capstone. Of these nine, four are exclusive to the Manufacturing Engineering major, two are taught by Manufacturing Engineering faculty, but are also required in other majors, two are taught by Industrial Engineering and Management faculty and one is taught by the Mechanical Engineering Department, but not required in the sister IE&M major. The collective content of these ten courses (nine plus a capstone) is what differentiates Manufacturing Engineering from other majors at NDSU.

It is to be noted that the course titles tend towards the traditional, with little overt identification with currently-popular methods for managing manufacturing technologies -- e.g., lean manufacturing, six-sigma, etc.. Similarly, there are no explicit course titles identified with the pillar for manufacturing competitiveness. Instead, these concepts are integrated into a fabric of more fundamental manufacturing engineering principles -- with the objective of preparing students for productive careers in the manufacture of any products made from any materials in any dimensional scale for any industry in any part of the world -- while, at the same time, serving the regional industrial economy.

Exclusive MfgE Courses
* CAD/CAM for Manufacturing
* Process Engineering
* Composites Manufacturing
* Production Engineering
* Product Realization Capstone

MfgE Courses, also taken by other majors
* Manufacturing Processes
* Automated Manufacturing Systems

IE&M Courses
* Quality Assurance and Control
* Production and Inventory Control

ME Course
* Engineering Materials

Figure 6: Courses that Differentiate Manufacturing Engineering at NDSU

The learning objectives of these ten courses correspond to instructional modules. Topical content of the modules has been analyzed and associated with one or more of the four pillars, to the detail of association with subsets of the pillar definition.

I: Materials and Manufacturing Processes
Ia -- materials
Ib -- manufacturing processes
II: Product, Tooling and Assembly Engineering
IIa -- product engineering
IIb -- tooling engineering
IIc -- assembly engineering
III: Manufacturing Systems and Operations
IIIa -- manufacturing systems
IIIb -- manufacturing operations
IV: Manufacturing Competitiveness

Figure 7: Legend for Associating Course Learning Objectives with Four Pillars

Mapping the content of the major-defining courses to the Four Pillars is fully detailed in the appendix, using the legend defined in Figure 7. The strategic purposes of this mapping are better presented in illustration form. The correlation of instructional content with the Four Pillars and their subsets, as defined in Figure 7, is depicted in bar-chart form in Figure 8. Partial application of a course to a pillar indicates that a portion of the topical content of the pillar is addressed in the course. For example, a particular course may address tooling and assembly engineering but not product engineering (Automated Manufacturing Systems) or may cover aspects of manufacturing operations, but not design of manufacturing systems (Quality Assurance and Control).

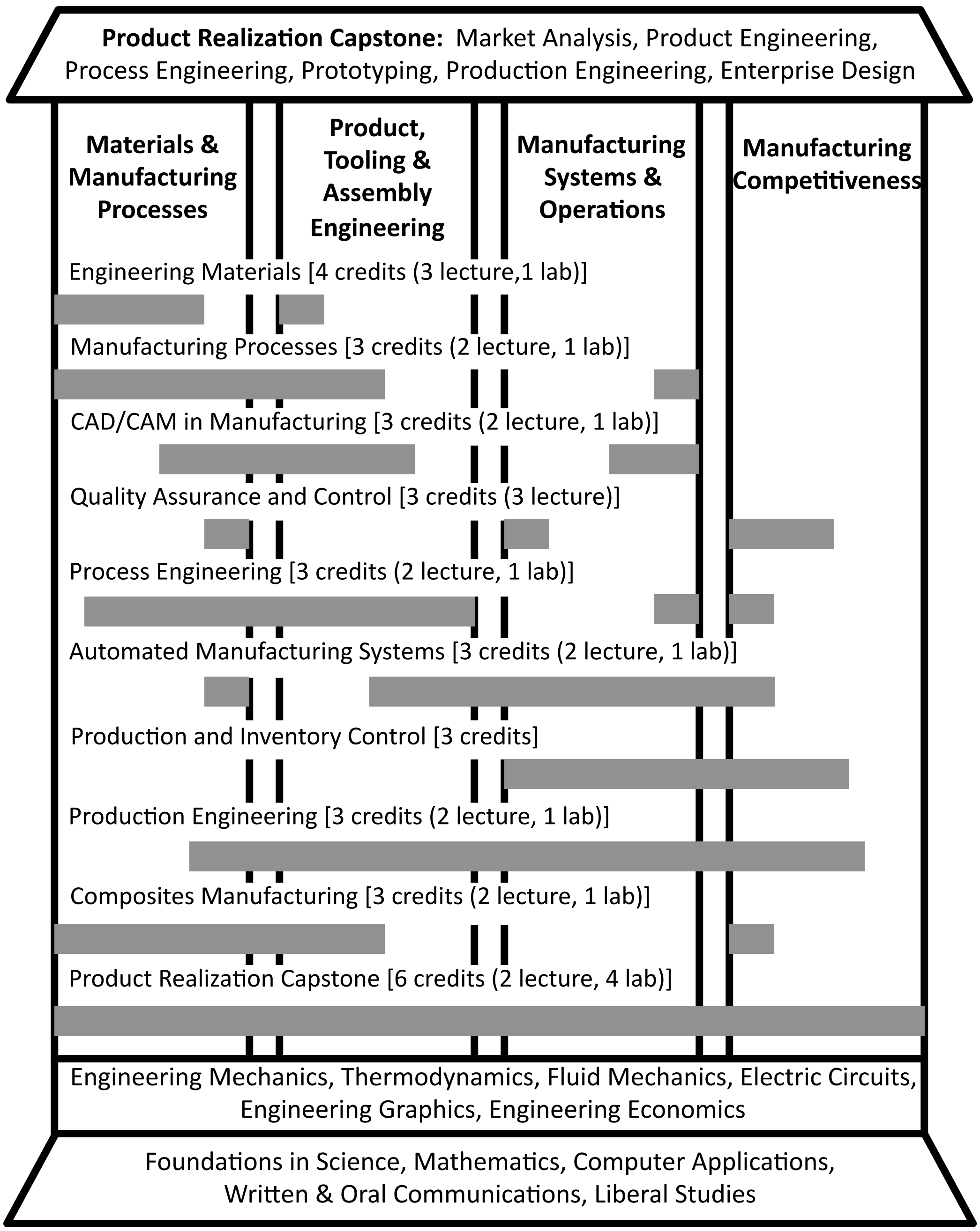

Figure 8: Mapping of Required Manufacturing Engineering Courses to the Four Pillars

Examination of the bar charting indicates that the curriculum as a whole maps quite closely to the content expected by the Four Pillars -- and, by association, by the accreditation program criteria. Eight of the pre-capstone courses contain modules that address one or more aspects of 'materials and manufacturing processes'. Seven required courses include instruction in one of more aspects of 'product, tooling and assembly engineering'. Likewise, seven courses include one of more aspects of 'manufacturing systems and operations'. In six pre-capstone courses, students are schooled in one or another aspect of 'manufacturing competitiveness'. In addition, the 'product realization' capstone is a comprehensive learning experience that spans all of the pillars in significant depth.

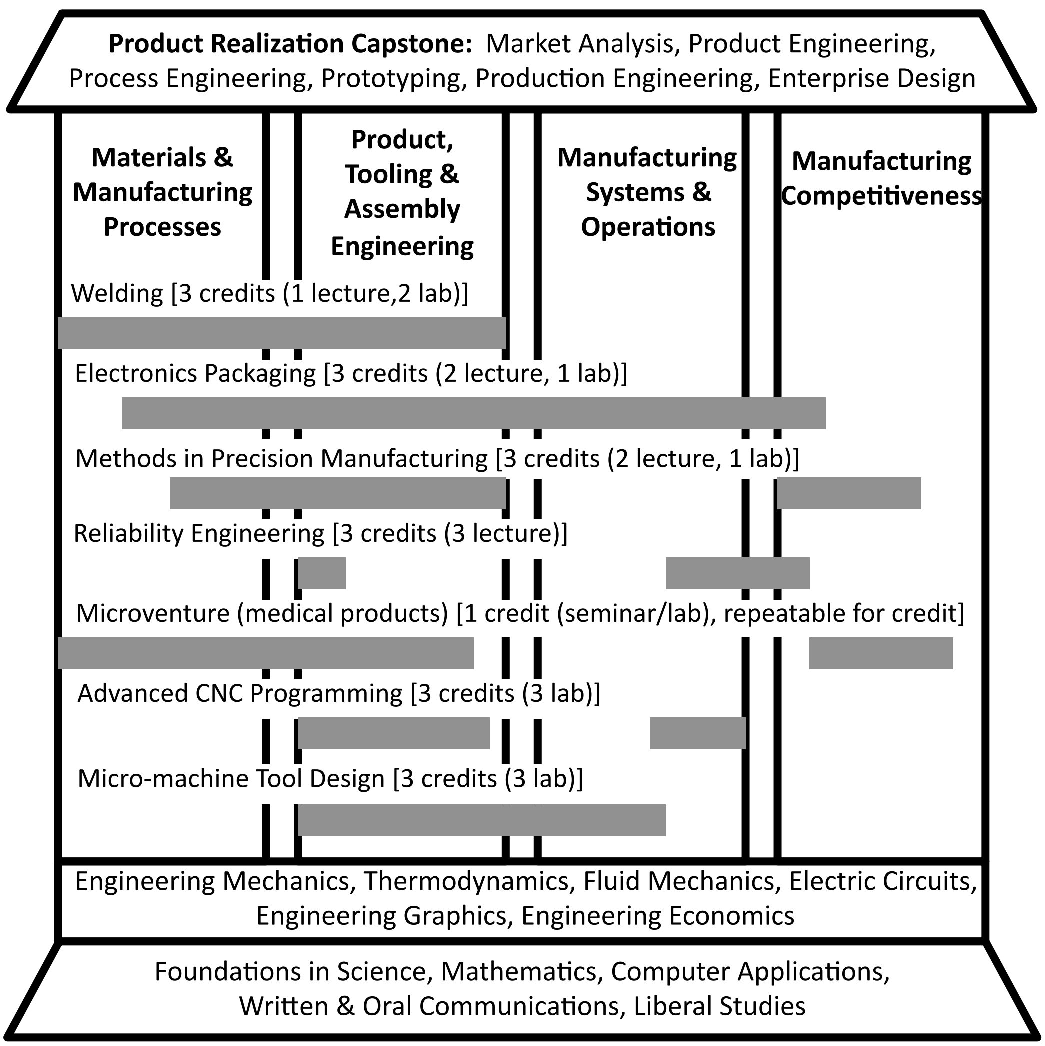

Figure 9: Mapping of Elective Manufacturing Engineering Courses to the Four Pillars

Technical elective courses are also mapped to the Four Pillars. This is not as crucial for accreditation evaluation, as not all students will take all of the electives and no elective is likely to be chosen by all students. Nonetheless, it is valuable to examine the thrust and content of elective courses in the same spirit as done for required courses. The result is quite similar: content of the electives also maps well to the Four Pillars and the accreditation program criteria.

Assessment and Continuous Improvement: The dominant outcome of this analysis is positive. The Manufacturing Engineering curriculum tracks with the Four Pillars very well, and it is clear that the related program accreditation criteria are fully satisfied. In addition, this analysis found that the fundamental factors intended to be integrated throughout the curriculum have, in the large, been successfully so treated. This seems especially true for integration of matters of quality and lean manufacturing. These two topical areas are addressed in numerous courses -- in the context of the broader subject matter. It is also noteworthy to reflect that a significant number of recent graduates have attained positions as quality managers, continuous improvement coordinators, black belts and the like in their professional employment.

The most important flaws uncovered in the curriculum are in the engineering materials course and the product realization capstone. The course in Engineering Materials now included in the curriculum is taught by the Mechanical Engineering Department. It has a very different purpose than that suggested by the Four Pillar model. There is also a long prerequisite chain for this course, which effectively places it as a late-junior-year experience. The purposes of a Manufacturing Engineering program would be better served by a course focused on 'materials for manufacturing' and accessible by early-sophomores or late-freshmen.

While highly effective in its application, the product realization capstone is limited in its reach to every student in the major. This course is very faculty-intensive in its current form. The typical format is a three-hour weekly class meeting, with a format paralleling a product development project in a modern industrial firm. Teams have numbered between three and six students; so, the student-credit-hour production rate is much lower than a standard lecture course. There are no departmental, collegiate or university resources to support this type of instruction, and these courses are taught as voluntary (i.e., no compensation) overloads. The result is that there are simply not enough faculty resources to make this type of intensive capstone experience available to every student. It is quite clear that a better method of delivering a manufacturing-centric capstone experience is needed.

The other two cross-program fundamental matters emerge as also less-than-ideal. Measurement and evaluation of manufacturing processing parameters has been receiving increasing attention in the past few years, but it is observed that, in comparison with the strength of the curriculum in the Four Pillar headings, further improvements are still needed. The same can be said for communications skills. While manufacturing faculty have been placing stronger emphasis on writing and speaking capabilities in the past several years, it cannot be claimed that student achievements have been equal to those in topics more traditional central to the major discipline.

Moreover, as is to be expected of a fundamental analysis of this nature, certain structural shortcomings in the curriculum have emerged. Most immediately, the mapping of course-level learning objectives to the Four Pillars brought to light some mis-statements of objectives -- cases where the learning objectives articulated in course syllabi were found to be incomplete or less clear than should be. These will be corrected for the next offering of the effected courses. While the effects on course content will be small, clarity in objective and delivery will be enhanced.

Certain measures that are not well-addressed by precursor guidance developed over the years by SME also attained new clarity through this analytical exercise. It became clear that none of the foundation works (core knowledge stems; program accreditation criteria; four pillars) provides for explicit inclusion of internationalism in instruction, and in an era of increasingly global manufacturing, this is clearly an important fundamental. While this matter could be integrated in similar fashion as matters of quality, the available curricular guidance is not clear on this issue. A similar observation applies to multi-disciplinary experiences for students. Another trend in modern manufacturing enterprises is that of multi-disciplinary teaming, and suitable practice in this regard ought to be incorporated into undergraduate curricula. Team-based project work is thoroughly integrated into the Manufacturing Engineering program, but this is primarily confined to in-the-major courses. While some students at NDSU gain invaluable multi-disciplinary experience through certain elective courses, added emphasis could (and should) be applied.

Some minor shortcomings in the Four Pillars model also come to light. Recall that the construct of the Four Pillars is oriented to the 'product producing enterprise', and the adaptation to the educational feeders for the enterprise is slightly secondary. As such, it is noteworthy that the Four Pillars do not explicitly address laboratory content in an educational program -- program criterion [e] laboratory experience: *measurement of manufacturing process variables in a manufacturing laboratory, manufacturing facility or realistic simulation and extraction of technical inferences about the process*. Likewise, the Four Pillars do not provide much direct visibility to the fundamental topics that should be distributed throughout any modern Manufacturing Engineering curriculum -- e.g., quality, lean manufacturing/enterprise, communications/documentation.

These are not fatal flaws in the Four Pillars model, by any measure. The model remains a powerful and effective tool for analyzing, guiding and assessing curricula in Manufacturing Engineering. Mapping such as reported in Figures 8 and 9 herein, if done rigorously, can serve as excellent tools for visualizing the cumulative effectiveness of a curriculum. Attention might well be directed, however, to refinements to make more visible those elements that are less explicitly addressed in the current version of the Four Pillars construct.

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Appendix: Manufacturing Engineering at North Dakota State University; Mapping of Course Learning Objectives to the Four Pillars of Manufacturing

Legend:

Learning objectives in individual courses map to the Four Pillars, identified in shorthand as follows:

Ia -- Materials
Ib -- Manufacturing Processes
IIa -- Product Engineering
IIb -- Process Engineering
IIc -- Assembly Engineering
IIIa -- Manufacturing Systems
IIIb -- Manufacturing Operations
IV -- Manufacturing Competitiveness

* -- course taught by faculty from Industrial Engineering and Management segment of IME Department
** -- course taught in Mechanical Engineering Department

Required Courses

Engineering Materials [ME 331**]

** Students must gain a Materials Engineering vocabulary -- Ia
** Students must have an understanding of Materials Engineering topics, e.g., mechanical testing, strengthening mechanisms, and heat treatment -- Iab
** Students must possess an understanding of various materials systems, e.g., ferrous, non-ferrous, ceramics, composites, and polymers -- Ia
** Students must recognize necessary considerations for informed material selection -- Ia,IIa
** Students must be able to problem solve and use critical thinking in lab design and material selection/properties -- Ia,IIa
** Students must recognize typical materials testing procedures as accepted industry standards -- Ia

Manufacturing Processes [IME 330]

- Identify and describe basic characteristics and applications of conventional and non-traditional manufacturing operations for individual parts and assemblies; -- Ib
- Identify critical process variables and their effect on process performance and product quality for basic manufacturing operations; -- Ib;IIa
- Select an appropriate manufacturing process and a sequence of operations under specific manufacturing constraints, given an engineering definition of a metal part; -- Ib,IIb,IIIb
- Apply the principles of Group Technology to design the process plan for a simple part belonging to a part family; -- Ib,IIa
- Select an appropriate set of process parameters, tools, and equipment for a specific manufacturing operation; -- Iab,IIIb
- Implement a process plan in a machining cell to manufacture a small batch of parts; -- Ib,IIb,IIIb
- Evaluate the quality of machined parts and the capabilities of the manufacturing process and/or operation used to fabricate these parts and suggest corrective actions, if needed. -- Ib,IIb,IIIb

CAD/CAM for Manufacturing [IME 380]

At the successful completion of this course, the students should be able to:

- Know the importance of design specification issues such as dimensioning and tolerancing; -- IIa
- Understand the computer graphics principles behind modern CAD/CAM software; -- IIb
- Use a start-of-the-art CAD/CAM software for part design and the generation of numerical control (NC) code for NC machines; -- Ib,IIb
- Write NC part codes for various machining operations; -- Ib,IIb,IIIb
- Use electrical motors to implement the motion control, and distinguish the open-loop and closed-loop control systems in NC machines; -- IIb
- Identify where, when and how to use CAD/CAM to improve a manufacturing system. -- IIb,IIIa

Quality Assurance and Control [IME 461*]

This course provides an introduction to statistical tools and techniques available for defining, monitoring, and improving quality and reliability of products, processes, and services. Topics include statistical control charts, process capability analysis, acceptance sampling, application of design of experiments for product and process optimization, and Taguchi methods. -- IIac,IIIa,IV

Process Engineering [IME 430]

At the conclusion of this course, the successful student should be able to …

1. … create comprehensive physical and analytical models of selected manufacturing processes, and employ those models in manufacturing process design and as decision-support tools for production of parts from a variety of engineering materials; -- Iab,IIb
2. … identify and describe the primary factors and activities in the processing cycle for discrete hardgoods; -- IIab
3. … clearly describe and graphically portray fundamental methodology for process engineering and for manufacturing process design; -- IIb
4. … design and conduct experiments in the machining behavior of a variety of engineering metals, and interpret the measured data in terms of workpiece characteristics and processing methods; -- Iab,IIb,IIIb
5. … identify, assemble and interpret the necessary data and information for designing processes for hardgoods production; -- Ib,IIab
6. … create and present effective written and oral reports of complex engineering projects. -- IV

Automated Manufacturing [IME 482]

Having successfully completed this course, the students should have:

1. Have the knowledge to identify the automation techniques and understand their principles used in a manufacturing system; -- IIIa
2. Have the knowledge on how to improve a manufacturing system by adding control and automation technologies; -- IIIa
3. Use PLC to develop a simple control system to integrate the sensor, actuators and other controllers; -- IIbc,IIIa
4. Write NC part code for simple machining operations; -- Ib,IIb
5. Control and program robots to perform simple movements for materials handling; -- IIIb
6. Understand how to integrate sensors, controllers, and computer network to capture and transmit data in a production system. -- IIIab,IV

Production and Inventory Control [IME 480*]

At the successful completion of this course, the students should be able to:

1. Understand the different manufacturing environments and their effects on production and inventory planning and control systems. -- IIIa,IV
2. Become familiar with product demand characteristics and the importance of demand management and forecasting principles and techniques. -- IIIab,IV
3. Understand the role of purchasing function and the important factors to consider for the development of partnership-type supplier programs. -- IIIb,IV
4. Understand the fundamentals of material requirements planning system and execution including problem domains, basic decision support models and opportunities. -- IIIb,IV
5. Apply innovative theories and techniques such as Just-In-Time and Theory of Constraints to design production systems. -- IIIa,IV
6. Understand the system approach to effective management of production and inventory through the applications of the principles of production and operations management. -- IIIb,IV
7. Use productivity assessment tools to evaluate the effectiveness of production and inventory management policies and practices of a firm. -- IV
8. Enhance their ability to be effective team members emphasizing contribution, project management skills, integrity, ethics, diversity, and personal growth. -- IV

Production Engineering [IME 431]

At the conclusion of this course, the successful student should be able to …

1. … articulate the principles of the Theory of Constraints and of cellular manufacturing; -- IIIa,IV
2. … create and evaluate comprehensive models of production systems for discrete hardgoods, based upon the physics of material-tool interactions, and upon the principles of constraints theory and cellular manufacturing; -- Iab,IIabc,IIIa
3. … identify, locate and interpret data for development of estimates of production demand for a selected product; -- IIa,IV
4. … clearly describe and graphically portray a fundamental methodology for design of production systems for manufacture of discrete hardgoods; -- IIIa
5. … design and predict the operational performance of a production system for serial manufacture of a selected product family; -- IIIab,IV
6. … identify fixturing needs, and design effective fixtures, for machined parts and/or products of moderate complexity; -- IIbc
7. … identify, assemble and interpret the necessary data and information for designing production systems used for serial manufacture of hardgoods. -- IIIa
8. … create and present effective written and oral reports of complex engineering projects. -- IV

Composites Manufacturing [IME 432]

If you have mastered the content and skills designed for this class, at the conclusion of this course you should be able to:

- Define advantages and drawbacks of composites over traditional engineering materials; -- Ia
- Understand the common types of reinforcements, matrices, and constituent composite material forms like fabrics, prepregs, compounds; -- Ia
- Identify the composite material systems based on their characteristics and applications; -- Ia
- Select an appropriate manufacturing technique and equipment for given composite material and justify their choice in terms of feasibility, production cost and rate; -- Iab,IIb
- Know the post-processes of composite materials to make mating parts by machining and assembly structure by joining; -- Ib,IIbc
- Understand the basic design knowledge about polymeric composite based on mechanics of materials, and use a software for composite materials analysis; -- Ia
- Perform cost analysis in selecting a proper composite material for a particular application. -- IV

Product Realization Capstone [Engr 489]

At the conclusion of this course, the successful student should be able demonstrate operational abilities to …

1. … develop quantitative and qualitative definition of the market segments for a designated product and of the characteristics of typical customers in each applicable market segment; -- IV
2. … design a functional product to fulfill specified market objectives, including complete and explicit specification and characterization of a component subsystems and parts; -- Ia,IIa
3. … completely specify the required manufacturing processes and/or purchasing specifications for all parts in a designated product; -- Ib,IIbc
4. … specify and design a functional prototype of a production-model product and a test program to evaluate both product and processing characteristics; -- Ia,IIa
5. … fabricate and evaluate a prototype of a production-model prototype; -- Iab,IIabc,IV
6. … specify and design a comprehensive production system for serial manufacture of explicitly designated products at an estimated production demand; -- IIIab
7. … design a complete manufacturing enterprise for acquisition of raw materials, production of goods, and sales and distribution of finished products to identified market segments; -- IV
8. … document analysis of markets and design of products, processes and a production system for technical, business and intellectual property purposes. -- IV

Elective Courses

Welding [IME 335]

- Be familiar with both oxy-acetylene and arc welding safety issues. -- Ib,IIc
- Be knowledgeable of basic facts concerning the history and development of welding. -- Ib,IIc
- Be able to explain and apply selected welding processes. -- Ib
- Be knowledgeable of weld testing. -- IIc
- Understand welding terms and welding symbols -- IIa
- Demonstrate practical skills in flat, horizontal and vertical welding positions using OAW, SMAW, GMAW, FCAW, AL-GMAW, GTAW processes -- Ib

Packaging for Electronics [IME 427]

At the conclusion of this course, the students should be able to:

- Describe the manufacturing procedures for chip packaging -- Ib
- Select an appropriate material for the printed wiring board -- Ia
- Identify an appropriate technology for fabrication of the printed wiring board or substrate -- Ib,IIa
- Describe the major methods for board-level packaging -- Ib,IIIb

- Be familiar with the advanced packaging technologies such as MCM, SoP, SiP, direct-die attach, 3D packaging, etc. -- Ib,IIIab
- Recognize the importance of quality and reliability studies in the electronics packaging industry -- IV

Methods in Precision Manufacturing [IME 437]

At the end of this course, the successful student should be able to…

1. Describe the principles and basic characteristics of selected methods for precision micro- and nano-scale manufacturing; -- Ib
2. Demonstrate an understanding of the advantages, limitations, and applications of contemporary methods for precision manufacturing; -- IV
3. Select candidate advanced materials for application in specified precision miniature parts; -- Ia, IIa
4. Select appropriate advanced manufacturing methods required to fabricate a precision miniature part or an assembled product made of traditional and/or advanced engineering materials; -- IIac
5. Specify the necessary parameters for design of a processing solution for manufacture of precision miniature parts. -- Ib

Reliability Engineering [IME 463*]

The course will provide the students with tools and techniques that can be used early in the design phase effectively influence a design from the perspective of system reliability. The course is designed to provide an intense understanding of reliability engineering tools in order to give a thorough philosophical and mathematical base for reliability engineering along with examples of application. Students completing this course will have good understanding of the actions and goals of a state-of-art reliability program and will become familiar with current techniques and their use. -- IIa,IIIb,IV

Bison Microventure [IME 494-01]

At the conclusion of this course, the successful student should be able have developed skills and competencies in …

1. … translating laboratory research into commercial products and/or processes; -- IV
2. … creating and maintaining intellectual property; -- IV
3. … applying micro-technologies in medical and dental devices. -- Iab,IIabc

CNC Programming [IME 494-02]

At the conclusion of this course, the successful student should be able to …

1. … create paperless direct digital manufacturing files; -- IIab
2. … create CNC programs for machined parts containing internal and external features and x-y and x-y-z curvilinear feature shapes; -- IIb
3. … execute direct digital manufacturing files to produce sample parts via additive manufacturing methods and via CNC machining. -- IIabc,IIIb

Design of Micro Machine Tools [IME 494-03]

At the conclusion of this course, the successful student should be able to …

1. … describe the necessary components of a high-precision milling machine for creating machined features in the micro- and meso-scale range; -- Ib,IIb,IIIb
2. … create a qualitative and quantitative definition of a selected sub-system capable of integration into a micro machine tool; -- IIb
3. … describe the content of prior work in the subject sub-system that has been reported in the professional literature; -- IIbc
4. … create a preliminary engineering design of the selected sub-system. -- IIb