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Using the Four Pillars of Manufacturing Engineering Model to Assess Curricular Content for Accreditation Purposes

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Abstract

Many manufacturing programs seek accreditation from ABET[1] (formerly The Accreditation Board for Engineering and Technology) and ATMAE[2] (The Association of Technology, Management, and Applied Engineering). Both ABET and ATMAE provide accreditation standards, proposed and endorsed through professional organizations such as the SME[3], that are used for self assessment by manufacturing programs. On a regular basis ABET and ATMAE evaluate compliance of accredited programs, including visiting institutions to review assessment processes for program outcomes. Most manufacturing programs welcome the external review to validate their efforts.

The Four Pillars of Manufacturing Engineering (Four Pillars) model was developed in 2011[4]. It provides a clear graphical outline of the core content of manufacturing programs. The four pillars model has been adopted by the accreditation groups in ABET and ATMAE, through the SME. The four pillars model groups specific knowledge and skills into topic- and process-based categories. The content of the Four Pillars model has been related to industry practices including a recent study by Nutter[5]. Therefore, an assessment plan that maps an academic curriculum to the four pillars can directly establish an industry relevance.

This paper outlines a process for assessing the curricular content for programs using the Engineering Accreditation Criteria (EAC) of ABET, that is framed by the Four Pillars model. The process could be easily modified for programs using the Technical Accreditation Criteria (TAC). The process includes forms for collecting outcomes content data in courses[6], input from industry stakeholders[7], and more. These instruments relate the results from the assessment data to the four pillars model, and can simplify and focus the review and reporting for accreditation purposes. Programs that choose to use the Four Pillars model for framing the assessment process will be able to use this paper to simplify the development of internal documentation for outcomes assessment.

ABET Accreditation

Accreditation through ABET requires regular, on-going input from stakeholders in order to demonstrate continuous improvement and relevance of the curriculum. The accreditation criteria themselves are the subject of continuous review and refinement by the professional bodies (ABET and the SME). The criteria are a combination of several factors[8] including statements specific to the discipline, and general criteria common to all engineering disciplines[9, 10] (listed on the left side of Table 1). Programs are also encouraged to extend these criteria to suit their particular niche and stakeholders. [university] specifically assesses both the manufacturing-specific (identified as criteria l-p in Table 1) and the general (ABET-specified a-k) criteria. The specific criteria for manufacturing programs are written as:

> Program Outcome Criteria for Manufacturing and Similarly Named Programs[10]
>
> > The program must prepare graduates to have proficiency in (a) materials and manufacturing processes: ability to design manufacturing processes that result in products that meet specific material and other requirements; (b) process, assembly and product engineering: ability to design products and the equipment, tooling, and environment necessary for their manufacture; (c) manufacturing competitiveness: ability to create competitive advantage through manufacturing planning, strategy, quality, and control; (d) manufacturing systems design: ability to analyze, synthesize, and control manufacturing operations using statistical methods; and (e) manufacturing laboratory or facility experience: ability to measure manufacturing process variables and develop technical inferences about the process.

The Four Pillars of Manufacturing Engineering Model

The Four Pillars of Manufacturing Engineering model[4] represents a professional perspective on the outcomes from a manufacturing program[11]. These group curricular areas by industry needs, as seen in Figure 1. Each of the four pillars represents a major area for manufacturing engineers. By definition, a manufacturing engineer must be educated in all of these topic areas. The bottom of the diagram lists fundamental knowledge and skills common to all engineering disciplines. The top level, the lentil, represents the skill sets specifically requested for manufacturing engineers. The content representing the foundation, lentil, and four pillars of the model are listed across the top of Table 1, and the ABET learning outcomes criteria are listed down the left side. This paper will discuss how the Four Pillars model can be used to effectively frame assessment of the ABET criteria.

The undergraduate curriculum is designed to demonstrate that the ABET learning outcomes criteria are realized by any graduate of the degree program. While delivery of a curriculum is developed and provided by the educational institution, industry has a better understanding of the more pragmatic Four Pillars model. The ABET criteria and the Four Pillars model have much of the same purposes, intent, and content, but the connection between the two is not immediately evident. A study was done in 2012 at North Dakota State University[12], showing how one manufacturing curriculum is aligned with the Four Pillars model. The following section of the paper outlines the relationship between ABET criteria and the Four Pillars model.

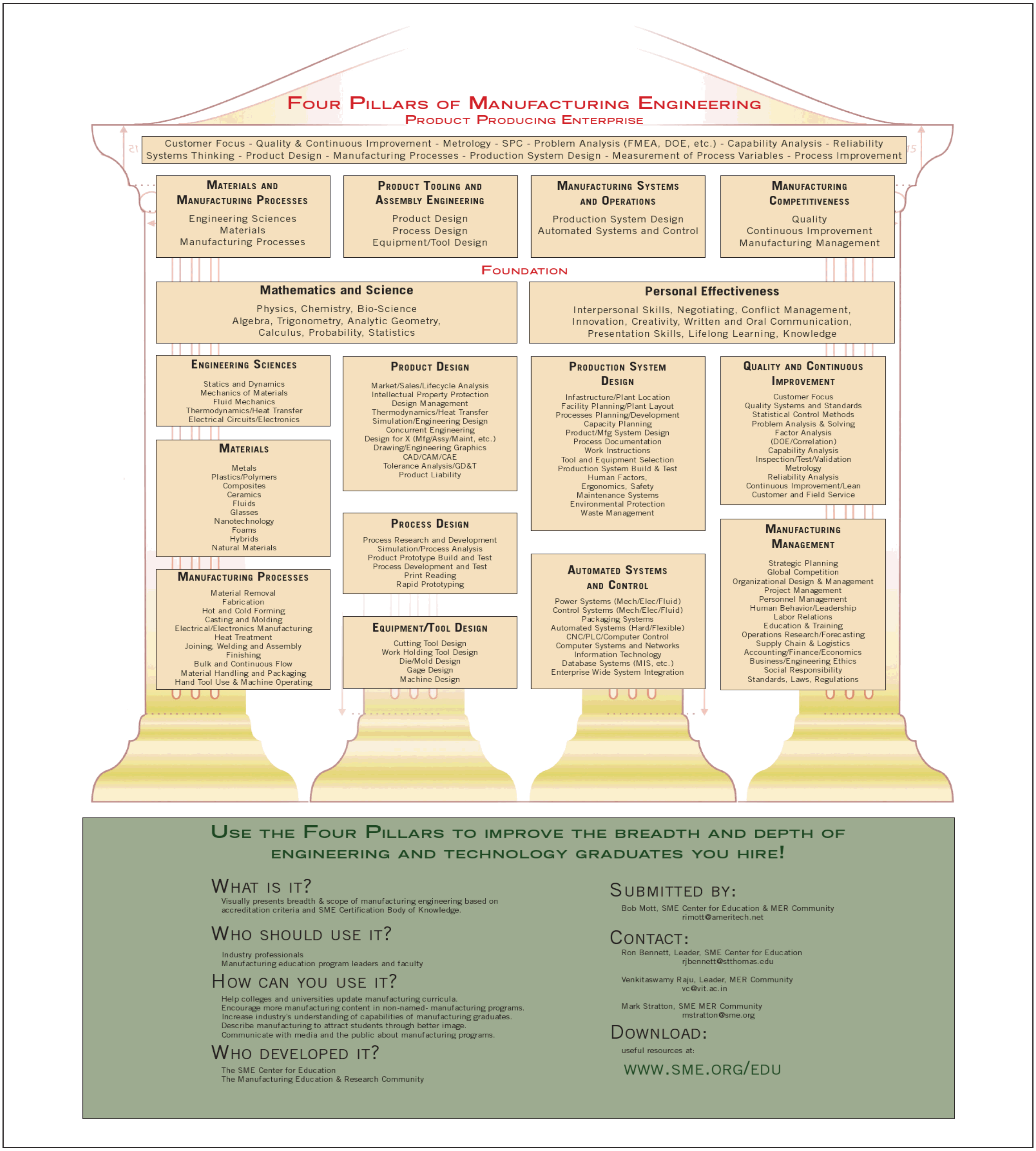


Figure 1 - Four Pillars of Manufacturing Engineering[4]

Mapping the Four Pillars to ABET

The Four Pillars of Manufacturing Engineering model is readily understood by practicing professionals, but may not be as clear to academics. For example ABET learning outcome (k) states that a graduate should have the "ability to use the techniques, skills, and modern engineering tools necessary for engineering practice"[10]. In order to obtain stakeholder feedback on this outcome, a questionnaire may include the following query: 'Please rank on a scale of 0 to 3, with 0 being unsure or unimportant, 1 = useful, 2 = important, and 3 = essential, the following statement: "ability to use the techniques, skills, and modern engineering tools necessary for engineering practice."' This rather vague question would most likely generate a great deal of scores in the 2-3 range, but provide little actionable data. However similar specific questions regarding knowledge, skills or abilities related to Metrology, SPC, or CAD would more likely yield actionable data. A mapping of the ABET general and manufacturing-specific learning outcomes and the Four Pillars model is a relatively straightforward exercise and can highlight areas of strengths and deficiencies in an academic program. A partial mapping of ABET learning outcomes to the Four Pillars of Manufacturing is included in Table 1.

Table 1 illustrates that a program that addresses the Four Pillars model also addresses the ABET learning outcomes criteria. Note that each row and column in Table 1 has at least one 'x' value. An empty row/column indicates an unsatisfied criteria. The large number of marks under the Lentil column indicates that the ABET criteria are well represented within the professional criteria presented in the Four Pillars model.

Assessing Content in Courses

Learning outcomes assessment in courses must occur on a regular basis to ensure that the net output from the curriculum matches the program objectives. One essential activity when assessing a course is to compare the actual outcomes to the planned outcomes. In the absence of any standards, this can be done by creating program-specific outcomes for each course. The Four Pillars model provides a framework of topics and structure that can be used for comparison of all courses in a manufacturing-based curriculum. No single course could ever satisfy all of the topics in the Four Pillars, however, upper level classes should normally have a clear focus on at least one of the Four Pillars. After assessment of learning outcomes, there is often a decision to make: no changes needed to course objectives, modify course objectives, or consider adding/dropping courses. Although most faculty will conduct this analysis as part of on-going teaching/course reviews, having a planned and documented process provides some structure, with a record of motivations, outcomes and proposed actions.

Table 1 - Map of four pillars block with references to items a-p

	Professional Competencies (Lentil)	Materials and Manufacturing	Processes Product, Tooling and Assembly Engineering	Manufacturing Systems and Operations	Manufacturing Competitiveness.	Fundamentals
		Engineering Sciences Materials Manufacturing Processes	Product Design Process Design Equipment/Tool Design	Production System Design Automated Systems and Control	Quality and Continuous Improvement Manufacturing Management	Mathematics and Science Personal Effectiveness
a. an ability to apply knowledge of mathematics, science, and engineering,			x			x
b. an ability to design and conduct experiments, as well as to analyze and interpret data,		x	x			
c. an ability to design a system, component, or process to meet desired needs,			x	x		
d. an ability to function on multidisciplinary teams	x					x
e. an ability to identify, formulate, and solve engineering problems,			x	x	x	
f. an understanding of professional and ethical responsibility,	x		x			x
g. an ability to communicate effectively,	x				x	x
h. the broad education necessary to understand the impact of engineering solutions in a global and societal context,	x			x		x
i. a recognition of the need for, and an ability to engage in life-long learning,	x		x			x
j. a knowledge of contemporary issues,	x			x		x
k. an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice,	x		x	x	x	
l. materials and manufacturing processes,	x	x		x	x	
m. process, assembly & product engineering,	x		x	x	x	
n. manufacturing competitiveness,	x	x			x	
o. manufacturing systems design, and	x	x		x		
p. manufacturing laboratory experience.	x	x		x		

ABET does not specify a method for assessing courses, therefore each program develops their own instruments. The instruments provided here use the Four Pillars model for assessing a course (see Figure 2 and Figure 3). At the completion of a course the instructor completes the form to capture the content that has been covered. The sample form provided is available on Google Drive[6] for use by any institution. When the form is completed, the results are saved to a spreadsheet on Google Drive. The results are then easily compiled and reduced. The Google tools also provide data analysis functionality so that collective sets of courses can be analyzed graphically, with pie charts and distributions. The comments sections allows instructors to provide important information and opinions that are less structured. The on-line form can be sent by email, and completed in 5 to 10 minutes. The simplicity of the instrument and method is key to obtaining regular and consistently formatted results quickly.

While the automated forms provided in Google Drive are convenient for data collection and compilation, a manual form alternative is shown in Figure 4. An unmarked version is available in Appendix A. This form was completed for a senior level course in PLC-based industrial control systems. Topical coverage is indicated using highlighting. Some judgement is required here, considering newness of material, depth of coverage, and maturity of student. This example demonstrates that there is good coverage of the controls and production systems. There is also coverage of other topics in the Four Pillars model, showing integration within the curriculum of multiple knowledge and skills areas. In this example, there are a number of topics from the processes group that are not covered, and therefore this instrument provides the platform to start discussions about possible course and curricular changes and improvements.

When assessing courses, it is important to remember that the Four Pillars model is not prescriptive. If necessary, topics should be added or removed to suit the program focus. The Four Pillars model should be used to communicate curriculum, not to limit it.

Instructor Course Assessment Form

This form is to be used by a course instructor at the end of each semester to track course content relative to the four pillars. Note that only the first three questions are mandatory. The data from this form is added for all courses for comparison to program objectives.
Note: Professional judgement is required. For example major treatment of a freshman mechanics topic may equate a minor treatment at the senior level.
Note: It is not necessary check 'None'

* Required

Course (e.g. EGR 345) *
We need to know what course is making the contribution

Instructor *
We need to need to know who is providing the input

When Offered (e.g. Winter 2014) *

Content: Engineering Sciences
Indicate the extent of coverage as it contributes to the curriculum.

	0=None	1=Trivial	2=Minor	3=Major
Statics and Dynamics	○	○	○	○
Mechanics of Materials	○	○	○	○
Fluid Mechanics	○	○	○	○
Thermodynamics and Heat Transfer	○	○	○	○
Electrical Circuits and Electronics	○	○	○	○
Other - (specify in comments)	○	○	○	○

Content: Materials
Indicate the extent of coverage as it contributes to the curriculum.

	0=None	1=Trivial	2=Minor	3=Major
Metals	○	○	○	○

Figure 2 - Instructor Course Survey Form - Top Portion[6]

Comments: Did the course run as expected?

Discuss how the course ran overall. If necessary discuss differences between the planned and actual course offering.

Comments: What changes are required?

What changes are required to the course? This may include updates, pedagogical innovation, outcome assessment.

Comments: Student preparation?

Were the students adequately prepared for the course? If not, what changes could be made in the prerequisites or this course?

Comments: Others?

Discuss anything of importance not covered in the other categories. If 'other' was selected for any of the topic content elaborate here.

Submit

Never submit passwords through Google Forms.

Figure 3 - Instructor Course Survey Form - Comments Section[6]

Professional Effectiveness

Customer Focus - Quality & Continuous Improvement - Metrology - SPC - Problem Analysis (FMEA, DOE, etc.) - Capability Analysis - Reliability - Systems Thinking - Product Design - Manufacturing Processes - Production System Design - Measurement of Process Variables - Process Improvement

The Four Pillars - The Four Core Areas

Materials and Manufacturing Processes

Engineering Sciences

Statics and Dynamics
Mechanics of Materials
Fluid Mechanics
Thermodynamics/Heat Transfer
Electrical Circuits/Electronics

Materials

Metals
Plastics/Polymers
Composites
Ceramics
Fluids
Glasses
Nanotechnology
Foams
Hybrids
Natural Materials

Manufacturing Processes

Material Removal
Fabrication
Hot and Cold Forming
Casting and Molding
Electrical/Electronics Manufacturing
Heat Treatment
Joining, Welding and Assembly
Finishing
Bulk and Continuous Flow
Material Handling and Packaging
Hand Tool Use & Machine Operating

Product, Tooling and Assembly Engineering

Product Design

Market/Sales/Lifecycle Analysis
Intellectual Property Protection
Design Management
Thermodynamics/Heat Transfer
Simulation/Engineering Design
Concurrent Engineering
Design for X (Mfg/Assy/Maint, etc.)
Drawing/Engineering Graphics
CAD/CAM/CAE
Tolerance Analysis/GD&T
Product Liability

Process Design

Process Research and Development
Simulation/Process Analysis
Product Prototype Build and Test
Process Development and Test
Print Reading
Rapid Prototyping

Equipment/Tool Design

Cutting Tool Design
Work Holding Tool Design
Die/Mold Design
Gage Design
Machine Design

Manufacturing Systems and Operations

Production System Design

Infastructure/Plant Location
Facility Planning/Plant Layout
Processes
Planning/Development
Capacity Planning
Product/Mfg System Design
Process Documentation
Work Instructions
Tool and Equipment Selection
Production System Build & Test
Human Factors, Ergonomics, Safety
Maintenance Systems
Environmental Protection
Waste Management

Automated Systems and Control

Power Systems (Mech/Elec/Fluid)
Control Systems (Mech/Elec/Fluid)
Packaging Systems
Automated Systems (Hard/Flexible)
CNC/PLC/Computer Control
Computer Systems and Networks
Information Technology
Database Systems (MIS, etc.)
Enterprise Wide System Integration

Manufacturing Competitiveness

Quality and Continuous Improvement

Customer Focus
Quality Systems and Standards
Statistical Control Methods
Problem Analysis & Solving
Factor Analysis (DOE/Correlation)
Capability Analysis
Inspection/Test/Validation
Metrology
Reliability Analysis
Continuous Improvement/Lean
Customer and Field Service

Manufacturing Management

Strategic Planning
Global Competition
Organizational Design & Management
Project Management
Personnel Management
Human Behavior/Leadership
Labor Relations
Education & Training
Operations Research/Forecasting
Supply Chain & Logistics
Accounting/Finance/Economics
Business/Engineering Ethics
Social Responsibility
Standards, Laws, Regulations

Foundation

Mathematics and Science

Physics, Chemistry, Bio-Science
Algebra, Trigonometry, Analytic Geometry,
Calculus, Probability, Statistics

Personal Effectiveness

Interpersonal Skills, Negotiating, Conflict Management,
Innovation, Creativity, Written and Oral Communication,
Presentation Skills, Lifelong Learning, Knowledge

Figure 4 - Manual Course Assessment Form - Marked for EGR 450 Manufacturing Control Systems

Incorporating Industry and Stakeholder Feedback

Manufacturing Engineering and Engineering Technology programs are particularly concerned with feedback from industry stakeholders. However, there is often a disconnect between the ABET learning outcomes as they are understood by faculty and industry. Therefore, a survey of industry stakeholders with questions which simply request relevance and ranking of the ABET a-k criteria is not likely to provide meaningful results. The real objective is to gather relevant information regarding the engineering program in question and how it serves the stakeholders. The amount of detail needed to make the survey relevant and understandable can make it too long and time consuming. In summary, a vaguely worded questionnaire, or very long detailed survey, is unlikely to receive a high response rate. To this end, the Four Pillars model provides a tool that is easily understood by both faculty and industry representatives, and allows for fast, detailed communication of needs.

A sample survey form is shown in Figure 5 and Figure 6[7]. The categories are based on the Four Pillars content, and align directly to the course assessment forms. Space is provided so that respondents may include free form responses that go beyond the constraints of the previous questions. Other questions are used for routine industry interaction. These forms can be emailed to industry stakeholders, as well as to other stakeholders in the program. The forms are completed and submitted electronically, with the results directly written to a spreadsheet.

The results from these forms can be compiled and summarized in order to understand which stakeholders and groups of stakeholders expect from the program and what changes if any they desire. A normal procedure may include sending these surveys out on an annual basis to companies and individuals identified as having an interest in the graduates and curriculum. The results can be compiled and used by faculty to assess and improve the program as required by the present and future needs of the community.

Stakeholder Survey: Manufacturing Curriculum Needs

This form will be used to compile a statistical model of curriculum needs. These results will be compared to our actual curriculum content.

Note: Keep in mind that this form is most useful when there are a variety of answers. For example, setting all answers to 'Essential' will make it impossible to determine priorities for change. We need to know where we can focus our limited resources.

* Required

Basics: Your Name *

We need to need to know who is providing the input.

Basics: Your Role and Company

Indicate who you are and your employer if applicable

Respondent Category *

Select the category that best reflects your role in completing this survey

- Member of the General Public
- Student
- Educator
- Professional - Independent
- Professional - Management
- Professional - Technical
- Other

Content: Engineering Sciences

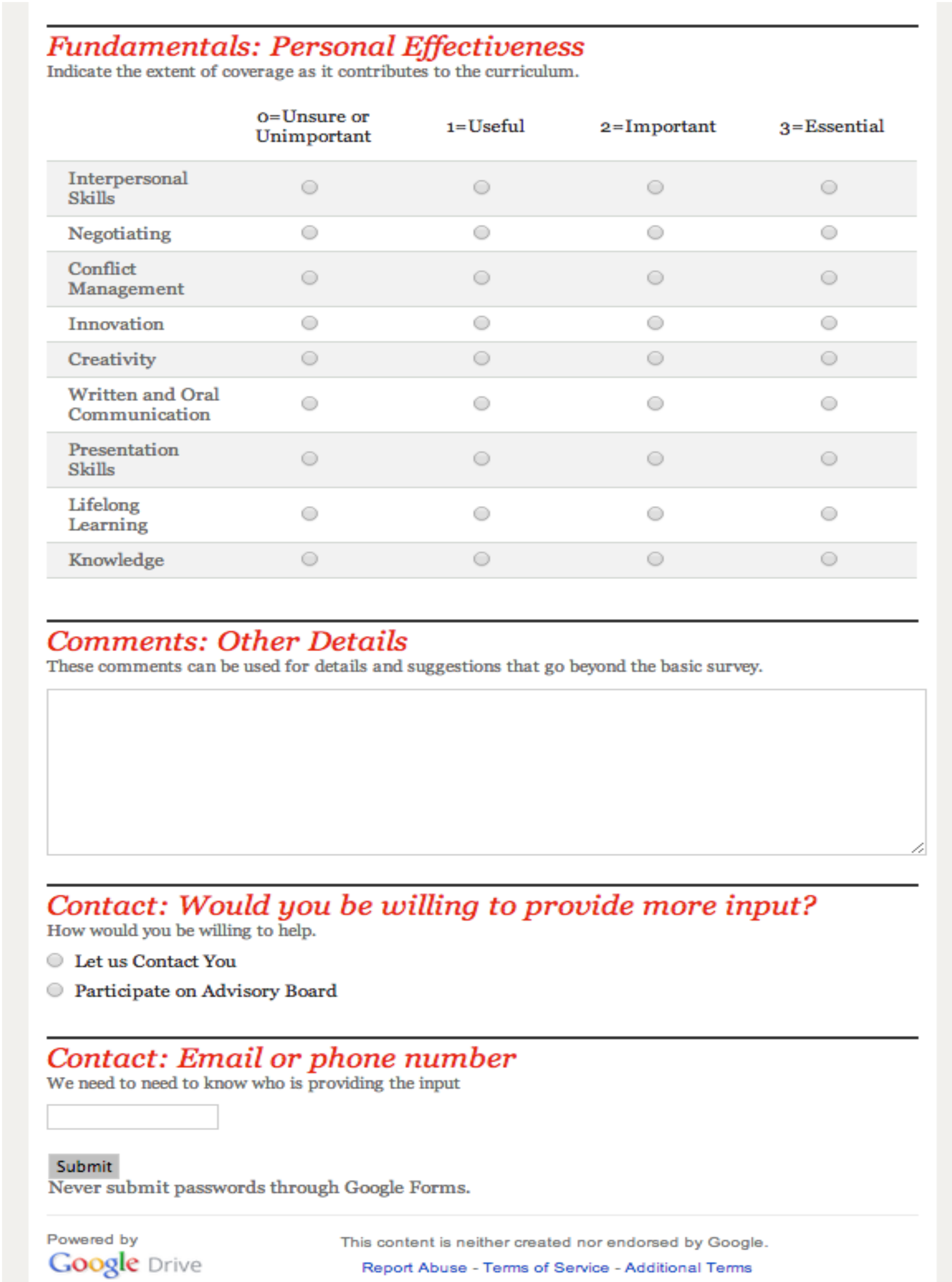
Indicate the extent of coverage as it contributes to the curriculum.

	0=Unsure or Unimportant	1=Useful	2=Important	3=Essential
Statics and Dynamics	○	○	○	○
Mechanics of Materials	○	○	○	○
Fluid Mechanics	○	○	○	○
Thermodynamics and Heat Transfer	○	○	○	○
Electrical Circuits and Electronics	○	○	○	○

Content: Materials

Indicate the extent of coverage as it contributes to the curriculum.

Figure 5 - Survey of Manufacturing Curriculum Need- Top Section[7]



Fundamentals: Personal Effectiveness

Indicate the extent of coverage as it contributes to the curriculum.

	0=Unsure or Unimportant	1=Useful	2=Important	3=Essential
Interpersonal Skills				
Negotiating				
Conflict Management				
Innovation				
Creativity				
Written and Oral Communication				
Presentation Skills				
Lifelong Learning				
Knowledge				

Comments: Other Details

These comments can be used for details and suggestions that go beyond the basic survey.

Contact: Would you be willing to provide more input?

How would you be willing to help.

- Let us Contact You
- Participate on Advisory Board

Contact: Email or phone number

We need to need to know who is providing the input

Submit

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Figure 6 - Survey of Industry Needs - Comments Section[7]

Assessing the Curriculum

Faculty are continually examining their courses and students for opportunities to improve. On an individual and course level, this is very healthy. Curriculum level assessment is more difficult because it requires participation from all faculty. The curriculum should be formally assessed a minimum of once per year, with a best practices goal being once per semester/quarter. In this process, the desired outcomes are considered. Many programs create a set of goals and objectives. The Four Pillars model is a reasonable alternative for capturing the technical objectives for the program. Regardless, the goals for the curriculum must be understood. For example, a goal that states, "The manufacturing program will prepare well rounded engineers with an emphasis on electronics processing," translates to an even coverage of the Four Pillars, but with topics added and deleted under the materials, processes, and design sections.

The objectives for the program should be compared to stakeholder needs, as determined by the survey. The differences between stakeholder objectives and curricular objectives are the gaps between academic and industrial expectations. Armed with knowledge of the gaps between curricular goals and stakeholder needs, the faculty can then decide which could, or should, be addressed. If the program is well designed and understood, the gaps should be predictable. Changes in these gaps suggest emerging industry needs. Note, a gap is an opportunity, but not all opportunities can be, or should be, pursued.

The individual course assessments should be compiled and then compared to the program objectives. Gaps between aggregate course outcomes and the objectives must be addressed. Typically a gap will be recognized as a transient issue, or require adjustments to program or course objectives.

In summary, the general annual assessment process using the Four Pillars is listed below. This assumes an existing curriculum.

1. Before Review
    - Communicate program goals using the Four Pillars model
    - Circulate stakeholder surveys
    - Faculty complete course assessment forms
2. During Review
    - Compile the course assessment data
    - Compile the stakeholder survey data
    - Compare the course and stakeholder data to the outcomes
    - Discuss differences. Prioritize importance.
    - Select high priority changes for courses and curriculum
3. Plan and Act
    - Adjust teaching or course content
    - Modify courses
    - Restructure curriculum

Conclusions

The Four Pillars of Manufacturing Engineering model is very valuable as a tool for supporting the ABET accreditation process for manufacturing programs. The ABET process is more universal in intent, while the Four Pillars model addresses manufacturing specifically. The program objectives, industry needs, and course outcomes can be examined objectively using the same measurement criteria. The Four Pillars model provides a topical framework that can be used and customized for any manufacturing engineering or technology program.

This paper includes examples of survey forms that can be adopted for use in curricular content review, in support of ABET accreditation procedures. This information can be used as the basis for a complete programmatic review, and offers an efficient and effective process for ongoing continuous improvement that is consistent with both academic and industry-based expectations.

Although not discussed in this paper, the Four Pillars model should be strongly considered by other engineering program with a manufacturing focus.

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Appendix A - The Four Pillars in Detail

Professional Effectiveness

Customer Focus - Quality & Continuous Improvement - Metrology - SPC - Problem Analysis (FMEA, DOE, etc.) - Capability Analysis - Reliability - Systems Thinking - Product Design - Manufacturing Processes - Production System Design - Measurement of Process Variables - Process Improvement

The Four Pillars - The Four Core Areas

Materials and Manufacturing Processes

Engineering Sciences

Statics and Dynamics
Mechanics of Materials
Fluid Mechanics
Thermodynamics/Heat Transfer
Electrical Circuits/Electronics

Materials

Metals
Plastics/Polymers
Composites
Ceramics
Fluids
Glasses
Nanotechnology
Foams
Hybrids
Natural Materials

Manufacturing Processes

Material Removal
Fabrication
Hot and Cold Forming
Casting and Molding
Electrical/Electronics Manufacturing
Heat Treatment
Joining, Welding and Assembly
Finishing
Bulk and Continuous Flow
Material Handling and Packaging
Hand Tool Use & Machine Operating

Product, Tooling and Assembly Engineering

Product Design

Market/Sales/Lifecycle Analysis
Intellectual Property Protection
Design Management
Thermodynamics/Heat Transfer
Simulation/Engineering Design
Concurrent Engineering
Design for X (Mfg/Assy/Maint, etc.)
Drawing/Engineering Graphics
CAD/CAM/CAE
Tolerance Analysis/GD&T
Product Liability

Process Design

Process Research and Development
Simulation/Process Analysis
Product Prototype Build and Test
Process Development and Test
Print Reading
Rapid Prototyping

Equipment/Tool Design

Cutting Tool Design
Work Holding Tool Design
Die/Mold Design
Gage Design
Machine Design

Manufacturing Systems and Operations

Production System Design

Infastructure/Plant Location
Facility Planning/Plant Layout
Processes
Planning/Development
Capacity Planning
Product/Mfg System Design
Process Documentation
Work Instructions
Tool and Equipment Selection
Production System Build & Test
Human Factors, Ergonomics, Safety
Maintenance Systems
Environmental Protection
Waste Management

Automated Systems and Control

Power Systems (Mech/Elec/Fluid)
Control Systems (Mech/Elec/Fluid)
Packaging Systems
Automated Systems (Hard/Flexible)
CNC/PLC/Computer Control
Computer Systems and Networks
Information Technology
Database Systems (MIS, etc.)
Enterprise Wide System Integration

Manufacturing Competitiveness

Quality and Continuous Improvement

Customer Focus
Quality Systems and Standards
Statistical Control Methods
Problem Analysis & Solving
Factor Analysis (DOE/Correlation)
Capability Analysis
Inspection/Test/Validation
Metrology
Reliability Analysis
Continuous Improvement/Lean
Customer and Field Service

Manufacturing Management

Strategic Planning
Global Competition
Organizational Design & Management
Project Management
Personnel Management
Human Behavior/Leadership
Labor Relations
Education & Training
Operations Research/Forecasting
Supply Chain & Logistics
Accounting/Finance/Economics
Business/Engineering Ethics
Social Responsibility
Standards, Laws, Regulations

Foundation

Mathematics and Science

Physics, Chemistry, Bio-Science
Algebra, Trigonometry, Analytic Geometry,
Calculus, Probability, Statistics

Personal Effectiveness

Interpersonal Skills, Negotiating, Conflict Management, Innovation, Creativity, Written and Oral Communication, Presentation Skills, Lifelong Learning, Knowledge