Session 2266

Synthesis of Engineering Best Practices and ABET AC2K into a New Mechanical Engineering Curriculum

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Abstract

Aggressive competition for global technological markets is driven by engineering breakthroughs in manufacturing and processing (micro/nano-electronics, data/information and materials), combined with new strategies that reduce risk, cost and time to market. This highly dynamic scenario is assisted by improved distribution systems like E-commerce, among others. Industry is aware that mergers and acquisitions by themselves do not guarantee world-class competitiveness but a great deal depends on their investment in a highly skilled workforce. As a consequence, industry is very interested in working with universities to raise their level of awareness on those competencies sought in new engineering graduates.

Engineering programs seeking to be relevant and responsive to industry and government agencies involved with hiring engineering graduates have no difficulties recognizing that, these employers represent an important component of their constituency. However, this group is not the only constituency that engineering programs seek/need to satisfy. Other constituencies are represented by alumni, professional associations, accreditation boards, departmental advisory boards, school directives, as well as, the students themselves.
All members of the program constituency do not agree universally on the priorities and which outcomes are better than others. Furthermore, less agreement exists on how to meet the challenges brought up by each.

This paper discusses the elements considered and the approach taken by the faculty of the Mechanical Engineering Department at Alabama A&M University, to synthesize into a new ME curriculum the ABET accreditation criteria 2000, the "best practices" recommended by the American Society of Mechanical Engineers, the recommendations of the Society of Manufacturing Engineers, the National Research Council recommendations and also those that have evolved from Boeing / University Key Schools Workshops.

As part of the competitive strategy, and to become relevant to regional needs, the concept for the new curricula was formulated with two specializations; one is focus on manufacturing and the other, is geared to propulsion systems. In both options areas such as; system performance, reliability, safety, concurrent engineering, teamwork and communication are given special attention.

I. Background

Alabama A&M University, (AAMU) was granted the authority to offer two new engineering programs in August 1, 1995. The mechanical and electrical engineering programs became a part of a larger legal desegregation law suit resolution in the civil case CV 83-M-1676. This situation brought to AAMU both a challenge and a unique opportunity to develop two engineering programs from "a clean sheet of paper" perspective. Dr. Arthur J. Bond, Dean of the School of Engineering and Technology, formed a team to develop both the electrical and mechanical curricula. This paper describes some of the elements that influenced the design of the new curricula for the Mechanical Engineering Program.

The first author was selected as a member of the team in 1996 and the co-authors joined the team in 1998. The program was approved in its entirety in October 1997. The court order forced a distinct and innovative focus to the program by requiring strict observance in its design, to be non-duplicative of any existing engineering programs in the state of Alabama. Two years after initial approval, the EE program graduated four students, and the ME program graduated two students that entered the program as transfer students from other institutions. Therefore, the ME program produced their first graduating class two years ahead of schedule. The two ME graduates hold manufacturing engineering positions in different local companies in the Huntsville area. There were approximately ninety students enrolled in the ME program at the initiation of its third year.

II. Problem Definition

The task of designing an innovative non-duplicative curricula for mechanical engineering is both a challenge and an opportunity to utilize the engineering design experience. This task was viewed as a multi-year project with a goal; to produce a competitive engineering program.

As in the case of new product development, it was essential to answer typical questions such as: a) What should be the key features; b) How to establish specifications; c) How to establish resource allocations; d) How to describe it; e) Who are the customers; f) How much would it cost; g) What should be the competitive strategy; h) What is the schedule and i) What are the risks and critical issues. Providing answers to these questions resulted in an effort to develop a synthesis of engineering best practices with ABET AC2K within the new mechanical engineering curriculum.

III. The Big Picture; Converging Views for a New Engineering Curricula.

A series of documents emerged by the mid-nineties that represented a national view on the subject of engineering education. These documents are enlightening and were helpful in developing the new ME curricula . A few points from them are discussed briefly herein.

National Research Council

In 1995, a report was issued on a new study conducted by the Board of Engineering Education (BEEd), of the National Research Council in cooperation with the National Aeronautics and Space Administration (NASA), the U.S. Department of Energy, the National Academy of Engineering, The Boeing Company, and Xerox Corporation.

For the authors, this report highlights emphasizing the view that engineering education should be that of a *systems perspective* requiring fluid and continuous interaction among school faculty, administration, professional societies, federal agencies, accrediting bodies and industry to produce the desired educational outputs.

Pertinent to curriculum design issues we can extract the following points:

- Development of a highly adaptable and flexible system
- Integration of both fundamentals with exposure to engineering practice and design
- Larger exposure to design principles, team projects, business perspective and societal issues.
- Training to perform well with interdisciplinary teams
- Tailoring to local circumstances keeping a global perspective.
- Assessment ready and open to industry’s feedback
- Reinforce communication skills experiences and training for life long learning.

In academe, gaining approval to curricular changes is at least a two year effort . As a consequence, meaningful changes will take approximately two to three years to have any influence to speak of. Since engineering programs are not required to show a return on investment in two or three years as industry is, it would be most advantageous to build-in flexibility and adaptability in the design of engineering curricula.

Some engineering programs here in the U.S., still debate the wisdom of the proposed changes given that: *It worked before, nothing has fallen off the table, if it isn't broke don't fix it , principles are non-changing, why should we*. However, if the engineering program is viewed as part of a dynamic system and every thing changes around it, then it would be reasonable to expect reflections of these changes in the curricula. Paradoxically in some nations of the pacific rim engineering programs are more aggressive in promoting rapid innovation and early specialized training.

ABET

By December of the same year, the Accreditation Board for Engineering and Technology (ABET) Board of Directors approved the Engineering Criteria 2000 for a two year period comment that began in January 1996. ABET Engineering Accreditation Criteria 2000 (AC2K) was approved for a three year phased implementation starting in the 1998-1999 accreditation cycle. AC2K provides guidelines for engineering programs to document: where they are now, and where improvements can be made in their programs. The interpretation of AC2K as a driver of innovation, reform, quality, and responsiveness to a constituency is still debated at the "trenches" ; however those more acquainted with the industry's efforts to remain competitive can note the parallelism between statistical control processes (SCP), and outcomes based assessment (OBA) predicated in AC2K.
ABET will still require one year of mathematics and basic science, a half year of humanities, and one and a half years of engineering topics as well as a capstone design experience.

Pertaining to the curriculum, ABET program criteria states: *Graduates most have demonstrated*:
a) knowledge of chemistry and calculus-based physics with depth in at least one;
b) ability to apply advanced mathematics through multivariate calculus and differential equations;
c) familiarity with statistics and linear algebra;
d) ability to work professionally in both thermal and mechanical systems areas including the design and realization of such systems"

AC2K has established in Criteria 3, eleven engineering competencies to be met. These are:

1 an ability to apply knowledge of mathematics, science, and engineering;
2 an ability to design and conduct experiments, as well as to analyze and interpret data;
3 an ability to design a system, component, or process to meet desired needs;
4 an ability to function on multi-disciplinary teams;
5 an ability to identify, formulate, and solve engineering problems;
6 an understanding of professional and ethical responsibility;
7 an ability to communicate effectively;
8 the broad education necessary to understand the impact of engineering solutions in a global/societal context;
9 a recognition of the need for and an ability to engage in life-long learning;
10 a knowledge of contemporary issues; and,
11 an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

AC2K also requires documentation that program outcomes and educational objectives have been met. ABET suggests use of: student portfolios, including design projects; nationally-normed subject content examinations; alumni surveys that document professional accomplishments, career development activities, employer surveys, and placement data of graduates.

ASME

Also in December of 1995, The American Society of Mechanical Engineers (ASME), issued a report entitled: Integrating the Product Realization Process (PRP) into the undergraduate curriculum. The report was documented by questionnaires sent to both industry and academe to determined what was considered as best practices utilized for the PRP. It also attempted to assess preparedness gaps as perceived by the industry. For most of the twenty-best practices in PRP, the responses tend to aggregate around preparation rated OK (Marginal).

The part that likely , provided more insight to the industry's views is the one section on comments from respondents on specific skills deficiencies perceived in new BS graduates. However, it is important to note that there is no indication to show that if this survey had been conducted five, ten, or fifteen years earlier that the results would be substantially different from those reported in 1995.

The list of twenty best practices opened for comments for the survey are:

	No. of comments generated
1. Teams/Teamwork	167
2. Communication	118
3. Design for Manufacture	116
4. CAD Systems	106
5. Professional Ethics	43
6. Creative Thinking	64
7. Design for Performance	16
8. Design for Reliability	129
9. Design for Safety	75
10.Concurrent Engineering	129
11. Sketching/Drawing	159
12. Design for Cost	159
13. Application of Statistics	89
14. Reliability	83
15. Geometric Tolerancing	132
16. Value Engineering	120
17. Design Reviews	140
18. Manufacturing Processes	142
19. Systems Perspective	124
20. Design for Assembly	39

It is logical to expect that respondents will be willing to be more vocal on subjects that are more often encountered in their workplace. It is somehow interesting to note that respondents will be almost twice as motivated to discuss views on Design for Reliability than plain Reliability. The most surprising from the list above is to find that the minimum number of comments go to Design for Performance. This data suggests that there may be a weak connection between reliability and performance which is certainly not true.

SME

On August , 1996 the Society of Manufacturing Engineers (SME), launched its Manufacturing Education Plan. As a result in 1997 SME and its Education Foundation produced a report entitled: Manufacturing Education Plan: Phase I Report. In this report the question of competency gaps among recent manufacturing engineering graduates and technologists were approached directly. SME has stated its interest in providing guidance on what, and how manufacturing topics should be taught.

Through a series of workshops the following top fourteen major competency gaps were identified and ranked:

1. Communication Skills (presentation skills, listening abilities, graphic software usage)
2. Teamwork (conflict resolution, interpersonal relations, team member, accountability)
3. Personal Attributes (leadership, sensitivity to others, consciousness of the big picture, ability to both teach and learn from others, analytical skills, and consensus building.)
4. Manufacturing Principles (lean manufacturing, concurrent engineering, constrains)
5. Reliability (Process and products, FMEA principles, testing for expected life cycles.)
6. Project Management (resource deployment, cross functionality, planning, monitoring)
7. Manufacturing Processes (gaps between “book learning” and application of principles)

CAD/CAM	Geometric Dimensioning and Tolerancing
Product Engineering	Materials
Blue Print Reading	Metrology
Hydraulics	Electronics
Process Improvement	Tool Design
Jig and Fixture Design	Troubleshooting

8. Business Skills (Cash flow, ROI, customer focus, risk analysis/management, etc.)
9. Quality (ISO 9000 compliance)
10. Change Management (long and short term perspectives, product configuration, control and documentation, acting as a change agent.)
11. Statistics and Probability
12. Ergonomics (human factors, safety and work station/tool design)
13. Materials (materials selection, manufacturability and utilization)
14. Continuous Learning or Lifelong Learning

It is commendable that SME has sustained the research regarding competencies. In their latest publication, ten professional and technical competencies have been identified. The list is: "business knowledge/skills, project management, written and oral communications, and international perspective, on the professional side; supply chain management, manufacturing process control, manufacturing systems, and quality on the technical side."

The aforementioned documents represent hundreds of man-hours of work among industry, academe, accreditation agencies and government agencies interested in providing assistance, and guidance in establishing where engineering education was back in 1995 with regard to industry's evolving needs.

The thrust of these efforts did not just happen almost simultaneously by accident, the National Science Foundation (NSF) funded several engineering school coalitions in the early nineties, to re-engineer the way engineering was taught. In a parallel effort, The Boeing Company launched in 1994 a series of initiatives to enhance engineering education. Boeing has sustained a high degree of involvement with the academic community via: internship summer programs, university/industry workshops and by appointing Boeing Executive Focal persons to work with "key" schools in the development of engineering competencies, that favor viewing engineering design as the central focus in engineering education.

IV. Regional issues and local constituency

ALABAMA A&M UNIVERSITY is located in Huntsville, AL., a region of major industrial manufacturing, technology transfer and research endeavors in space transportation and propulsion. AAMU is one of two Land Grant Universities in Alabama. A few highlights on the history of the state provides insights to activities that draw community support for engineering and research activities.

- Orville and Wilbur Wright carved part of aviation history in March 29, 1910 with their first flying school in Montgomery.
- Alabama is the home of the Tuskegee Airmen;
- Huntsville is the home of the Redstone Arsenal and the U.S. Army Aviation and Missile Command (AMCOM)
- Dr. Von Braun's team based in Huntsville, used a modified Redstone rocket to put America's first orbiting satellite into space.
- Alabama is the home of NASA's George C. Marshall Space Flight Center where the Mercury-Redstone vehicle was developed, and successfully launched Admiral Alan B. Shepard to a sub-orbital flight; making him America's first astronaut.
- NASA MSFC is a national center for propulsion research , space transportation and micro-gravity. Where the space station freedom started to be built.

V. Definition of the New Mechanical Engineering Curriculum

As a result of the consideration of the information discussed herein. It was concluded that, the resulting curriculum had to:

1. Meet accreditation criteria
2. Address national trends, while becoming locally relevant
3. Allocate space for university core requirements,
4. Stay as a four year program to be completed within 128 to 130 semester credit-hrs.
5. Provide flexibility
6. Be focused on teaching and instruction that reflects real engineering practice.
7. Be a competitive and cost effective program.

As part of the competitive strategy and to become relevant to regional needs, the concept for the new curricula was formulated with two specializations; one focused on manufacturing and the other geared to propulsion systems. To provide additional adaptability a third option was included as the general option with a group of elective courses to be defined as the system evolve. In both options areas such as; system performance, reliability, safety, concurrent engineering, teamwork and communication are given special attention.

As a means to illustrate the engineering practice, it is required that all engineering courses have at least one project . The projects are developed by students working in teams. The projects require a report and an oral presentation that has weight in assigning the final grade.

The design practice is integrated during the four years and culminates with two sequential senior level courses in mechanical engineering design.

Training for life long learning is achieved by teaching students about learning at different levels of complexity, as discussed by Bloom et all.

The new curricula is intended to reduce the time industry and government usually takes in the "re-training" of new engineering graduates to become part of a production team.

Two 200 level courses required in electrical engineering aim to facilitate the interdisciplinary work that mechanical engineers are faced on a daily basis.

The specializations provide sixteen semester-credit hours of course study in the specialized area. The work that students carry out is augmented by five semester credit hours of senior design in the respective specialization, bringing the total focus to twenty one credit hours of scholarly work in either the manufacturing or propulsion options.

Specially designed courses include: a) Introduction to Mechanical Engineering ;
b) Concurrent Engineering; c) Quality and Reliability Assurance; d) Design for Manufacture and Reliability; e)Economic Evaluation of Design Projects; f) Operations Planning and Scheduling; g) Power Systems Integration; h) Power Plant Performance;
i) Analysis and Synthesis of Gas Turbine Components; j) Gas Dynamics; and
k) Rocket Propulsion.

The proposed new curriculum became one that meets university core requirements, a core of common engineering courses until the third year and a senior specialized courses with a capstone design sequence. The curriculum is shown in the next page.

THE MECHANICAL ENGINEERING PROGRAM AT AAMU

Freshman Year

First Semester			*Sem. Hrs.*
ORI	101	Survival Skills	1
[1] ENG	101	Communication Skills I	3
MTH	125	Calculus I	4
CHE	101	General Chemistry I	3
CHE	101L	General Chemistry I Lab	1
		[3] Health Science	2
[4] EGC	101	Eng. Drawing & Graphics	3
			17

Second Semester			*Sem. Hrs*
[1] ENG	102	Communication Skills II	3
MTH	126	Calculus II	4
PHY	105	Physics I	4
[4]EGC	104	Computer Programming	3
ME	101	Intro to Mechanical Engineering	1
ME	101L	Intro to Mechanical Engin.Lab	1
			16

[1]ENG 103, or ENG 104 may be taken by international students.
[3]FAS 101, HED 101, or NHM 103
[4]The equivalent general engineering course can be substituted with the corresponding ME course.

Sophomore Year

First Semester			*Sem. Hrs.*
MTH	227	Calculus III	4
PHY	106	Physics II	4
HIS	101	World History I	3
EE	201	Linear Circuit Analysis I	3
EE	201L	Linear Circuit Analysis I Lab	1
ME	205	Statics	3
			18

Second Semester			*Sem. Hrs.*
MTH	238	Differential Equations	3
HIS	102	World History II	3
		[5] Social Science	3
ME	210	Material Science	3
ME	206	Dynamics	3
			15

[5]PHL 201, PSY 201, SOC 201, or GEO 213.

Junior Year

First Semester			*Sem. Hrs.*
ECO	200	Basic Economics	3
ME	231	Strength of Materials	3
ME	310	Thermodynamics	3
ME	320	Kinematics/Dynamics of Mach.	3
ME	360	Fluid Mechanics I	3
ME	360L	Fluid Mechanics Lab	1
			16

Second Semester			*Sem. Hrs.*
EE	203	Analog Circuit Des/Anal.	3
EE	203L	Analog Circuit Des/Anal. Lab	1
ME	300	Math. Meth. in Mech. Engin.	3
ME	301	Anal. & Instrum./Phys. Syst.	2
ME	301L	Anal. & Instrum./Phys. Syst.L	1
ME	312	Heat and Mass Transfer	3
ME	312L	Heat and Mass Transfer Lab	1
			14

Senior year Common Courses

First Semester			*Sem. Hrs.*
ENG	203	Humanities I	3
ME	451	Automatic Control Systems	2
ME	451L	Automatic Control Systems L.	1
ME	470	Mech. Engin. Design Project	2

Second Semester			*Sem. Hrs.*
ENG	204	Humanities II	3
		Art/Music Elective	3
ME	470A	Mech. Engin. Design Project	3
			9

Specialty courses in Propulsion Systems

ME	311	Power Systems Integration	3
ME	411	Power Plant Performance	3
ME	412	A/Synthesis of Gas Turb/Comp.	3
ME	412L	A/Synthesis of G. Turb/Comp. L.	1
ME	413	Rocket Propulsion	3
ME	416	Gas Dynamics	3

Specialty courses in Manufacturing

ME	370	Concurrent Engineering	3
ME	432	Design. for Manf. & Reliability	3
ME	432L	Design. for Manf. & Rel. Lab	1
ME	472	Economic Eval. of Design Proj.	3
ME	481	Qual. & Reliability Assurance	3
ME	482	Operations Planning & Scheduling	3

VI. Conclusion

A new curricula in mechanical engineering at AAMU has been designed with vertical and horizontal integration. Its design is intended to provide as much responsiveness to all the constituencies identified in the system. It aims to develop to some extent, in the ME students, part of the engineering competencies sought by industry and government, during a four year effort. The coursework includes training in design for : manufacture, performance, cost, reliability, safety, communications and team / teamwork skills.

The approach to building engineering competencies is promoted by hands on project development and specialized lectures and group exercises. Students seem appreciative of the characteristics of the program and have demonstrated a higher level of interest in pursuing their academic work.

Last year two students graduated from this program. One of the ME graduates was awarded the Outstanding Scholar Award in the School of Engineering and Technology. Both graduates have positions of responsibility as manufacturing engineers in the Huntsville-Decatur area.

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Appendix 1. List of engineering competencies reviewed.

Teams/Teamwork
Communication
Design for Manufacture
CAD Systems
Professional Ethics
Creative Thinking
Design for Performance
Design for Reliability
Design for Safety
Concurrent Engineering
Sketching/Drawing
Design for Cost
Application of Statistics
Reliability
Geometric Tolerancing
Value Engineering
Design Reviews
Manufacturing Processes
Systems Perspective
Design for Assembly
Design of Experiments
Project Management Tools
Design for Environment
Solid Modeling/Rapid Prototyping Systems
Design for Ergonomics (Human Factors)
Finite Element Analysis
Physical Testing
Total Quality Management
Design for Service/Repair
Product Testing
Process Improvement Tools
Tools for "Customer Centered" Design
Information Processing
Leadership
Statistical Process Control
Test Equipment
Industrial Design
Design for Commonality-Platform
Computer Integrated Manufacturing
Design Standards (e.g. UL, ASME)
Mechatronics (Mechanisms and Controls)
Testing Standards (e.g. ASTM)
Electro-mechanical Packaging
Conflict Management
Robotics and Automated Assembly
Design for Dis-assembly
Knowledge of the Product Realization Process
Process Standards (e.g. ISO 9000)
Competitive Analysis
Project Risk Analysis
Budgeting
Manufacturing Floor/Workcell Layout
Bench Marking
Corporate Vision and Product Fit
Materials Planning-- Inventory
Business Functions/(Mkt’g, Legal, etc.)

* List from ASME "Integrating the PRP into the Undergraduate Curriculum" 1995.