Session 1566

Development of Engineering Competencies in Freshman Courses

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Abstract

The mid-nineties has brought industry close to a unified view that benchmarking is fundamental for strategic planning and development of improved processes that increase competitiveness. Benchmarking is nowadays applied to both products, parts, services, as well as to personnel. Establishing where a company is and where they need to be to stay competitive can be considered a "technological gap." By working with industry, professional engineering societies have documented perceived competency gaps in newly hired graduates. It has been recommended to include the product realization process into the engineering curriculum, as well as, to incorporate "best practices" as a means to develop new knowledge, skills and attributes that industry seeks in new engineering graduates.

As engineering programs face increasing demands to alleviate the perceived technological gaps, the solutions have to be addressed in multi-year efforts. To facilitate the development of new engineering competencies, the authors have adapted/developed materials and examples for the introductory freshman course in Mechanical Engineering at Alabama A&M University. Goals of the course include but are not limited to: introduce freshmen students to the Product Realization Process, have the students develop a personal professional plan and to develop a basic engineering project to include market outlook, basic production techniques, economic assessment, planning, design, manufacturing, testing and product evaluation. From this point on students start their design practice portfolio. Building on these competencies continues through subsequent courses.

I. Background

Alabama A&M University, (AAMU) was granted the authority to offer two new engineering programs in August 1, 1995. The authorization to offer mechanical and electrical engineering programs was obtained as part of a larger legal desegregation law suit resolution in a 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 ME curricula and in particular the freshman course ME 101 Introduction to Mechanical Engineering.

The first author was selected as member of the team in 1996 and the co-authors joined the team in 1998. The introductory course has been offered three times with a corresponding laboratory (ME 101L) since 1997. Approximately sixty students in the ME program have taken the course and lab.

II. Introduction

ME 101 is an introductory course in Mechanical Engineering at Alabama A&M University designed to initiate the development of engineering competencies in engineering freshman. Engineering competencies in this paper are understood as a collection of criteria that reflects those practices that the graduating engineer will be most likely to encounter in their professional work. Without being complete, we find typically that industry appreciates training in design for manufacture/performance/cost/reliability/safety/assembly, communications and team / teamwork skills. Building these competencies is promoted by hands on project development, specialized lectures and group exercises.

Given that engineering professional work is not restricted to engineering design exclusively, the students are encouraged to identify a dozen or so criteria of engineering competencies from among a list of fifty that may be more in line with their expectations in terms of work functions when they seek employment. The list that is presented to the student is in appendix 1. The students are asked to self-establish a benchmark about what they perceive as mastery of those selected competencies in terms of percentage points. This is the initiation of their professional development plan. The plan represents the student's choice, and it is expected that the students will feel more comfortable, motivated, and eager to work towards the realization of their own plan.

The lecture is one credit hour and has as co-requisite a one credit hour laboratory listed as: Introduction to Mechanical Engineering Laboratory (ME101L).

The introductory course in mechanical engineering has been designed to:

* Provide a first hand experience about the engineering practice
* Provide an opportunity to first time freshman to work directly with the engineering faculty in their major, in their first year in college
* Build up interest in engineering endeavors to gain motivation to be successful in completing their calculus and physics sequences.
* Promote peer study group development
* Provide access to academic advising
* Be a showcase of topics that will be covered in full detail in subsequent engineering courses like statics, material sciences and fluid mechanics

The goals of the course are :

* To introduce freshmen students to the Product Realization Process (PRP)
* To have the students develop a personal professional plan
* To develop team skills, communication skills and creative thinking
* To practice problem solving of open ended problems
* To develop a basic engineering project to include market outlook, basic production techniques, economic assessment, planning and design, manufacturing, testing, and product evaluation.
* To have students started in their design portfolio.

III. Rational and General Approach

Development of engineering competencies in freshman courses is not viewed in a self-contained or modular package, but as a part of a larger integrated system. We consider the complete program in mechanical engineering as the system. For the development of the course material for ME101, we researched industry views and adapted training documents used in selected industries. Class material is reviewed by all the faculty members in periodic meetings during the semester. In the meetings faculty reviews group dynamics reaction to class discussions, if problems are perceived or not, and progress towards the goals.

The authors share the view that nowadays, engineering education is not an isolated activity restricted to engineering schools/colleges. We consider that a sound strategic plan in the engineering program shall consider all of the parts; infrastructure, human resources, constituencies input, university mission and a business plan (i.e. funding/financing). That is, we welcome a systems approach for planning. Therefore, we also support the view that the goals of strategic planning and development in the engineering program shall reflect the intended or desirable outcomes. This is consistent with the accreditation criteria referred herein as AC2K, developed by The Accreditation Board for Engineering and Technology (ABET).

ABET Criteria 3 has defined a list (a-k) as required program outcomes. The authors consider that some of the intended outcomes also should consider employment outlook, and near-term forecasts of emerging technologies; although, this kind of information is limited and difficult to assess.

ME 101 is part of the engineering program plan and as such the course outcomes may be defined in terms of a flow processes with closed loop feed-back mechanisms designed for process improvement. From its inception the introductory course pursues documenting goals, outcomes and results. These materials will serve in the review of the ME engineering program strategic plan. The intent is to provide a benchmark that can assist us to determine where we are with respect to our design requirements and goals for the ME101 course. The authors expect that as the engineering program with its processes evolves and it is iterated, its built-in feedback mechanisms will eventually show where improvements may be more advantageous.

The ME curricula at AAMU has been designed with vertical and horizontal integration and it is discussed in a separate paper. It should suffice to mention that as a result of the research and planning it became clear that an introductory course in mechanical engineering was strongly recommended in order to reach the program's proposed outcomes.

IV. Course Progress and Overview

ME 101 Introduction to Mechanical Engineering has no pre-requisites. It was initially offered in the Spring Semester only. The expected enrollment in the 1997-1998 academic year, was twenty five to thirty incoming freshman students. We were quite surprised that half of the students identified in the fall semester that were required to enroll in ME101 did not return the following semester. Subsequent investigation revealed that some students had difficulties with courses in chemistry, physics and calculus. University advising considered appropriate to advise students to change majors (leave engineering) if declared engineering majors had problems with the aforementioned courses. This produced a large drop-out rate. It was decided that ME 101 will be offered both in the Fall and in the Spring in order to capture all the incoming students declaring ME as their major.

The class is team-taught by two ME faculty members. Although building team skills is a major task, the class is not divided into formal teams from the onset. During the first two offerings of this class, freshmen were encouraged early to form teams without basic training in team formation. The result was that teams were unstable, some teams broke up and new teams were established by mid-semester. For subsequent offerings of the course, efforts are geared toward students building a consciousness about desirable characteristics of teams, rules of cooperation, decision making, and learning styles before the teams are formally constituted.

As part of the team rules, each student in the team is considered a mentor of each other.

Periodic evaluations, at instructor discretion, are made by the students of their respective mentors performance. The mentor evaluation forms are selected forms from work done by the University of Central Florida, evaluation forms of a senior/graduate design class.

The students are informed that they will develop a project, the project will include a final report and team presentation covering in story-like manner, topics such as: basic production techniques, economic assessment, planning and design, manufacturing, testing, and product evaluation.

V. Elements of the Course Mechanics

At the onset of the course, instructors review the mechanical engineering curricula with attention to the specializations offered. It is reviewed where the students are and what are the timelines for graduation.

The students are asked to become drivers of their learning process. Learning is presented in terms of Bloom's theory as presented in Taxonomy of Educational Objectives. Learning is presented as an iterative process with increasing levels of complexity or steps. The idea of cyclic model or learning has also been documented by David A. Kolb.
Following Bloom's model, the learning objectives are presented to students as progress towards a multi-path to new knowledge.

Our purpose is that the students be able to determine at what level of mastery of the subject/topic he/she are (i.e. benchmark their learning level) and be knowledgeable as to "what is next" for them to do. For example if the topic has been studied at an application level, the students will know that the next step is to do an analysis study.

This approach is the means through which students begin training for life-long-learning (L^3) which is part of the program goals.

In a simplified form it is explained as a merging of branches of knowledge as shown below:

Step	Learning Objective 1 (LO_1)	Learning Objective 2 (LO_2)	Learning Objective 3 (LO_3)
1st :	Knowledge of LO_1	Knowledge of LO_2	Knowledge of LO_3
2nd :	Repetition- LO_1	Repetition- LO_2	Repetition- LO_3
3rd :	Application- LO_1	Application- LO_2	Application- LO_3
4th :	Analysis – LO_1	Analysis – LO_2	Analysis – LO_3
5th :	Evaluation of LO_1	Evaluation of LO_2	Evaluation of LO_3

(The sixth step can occur in a directed combination or in a random permutation of LO's)

6th : Synthesis of LO_1 & LO_2 into LO_x Synthesis of LO_2 & LO_3 into LO_y

As a consequence of the synthesis of learning objectives, new knowledge is created and the cycle of learning can be repeated again. Development of new Learning Objectives are derived from the synthesis of previous LO's.

The instructor introduces the subject to be learned, the student is asked to repeat the idea, this demonstrates his/her level of understanding/ comprehension.
The instructor proceeds with applications and initiates analysis. Students as a group help to elaborate the analysis part. The instructor continues on evaluating the new subject and assists students on finding limitations on the subject/equation. Examples are given on the synthesis of new knowledge. For the ME101 class students are not expected to reach levels of synthesis in the topics covered. The list of topics or course contents description is included in appendix 2.

Homework is basically reading assignments in preparation for the following class. Almost all the examples and calculations are done in class with everyone participating. Examples require reading data form charts, tables and graphs, calculating percentages, average values and use of engineering conversion factors. Emphasis is made on technical vocabulary development.

The project of choice has been the design, fabrication and testing of a glider. The glider is designed to meet performance parameters (i.e. glide angle). The size of the glider as well as, the materials and methods of construction are open ended. Students are at liberty to select configuration and they can build more than one design. The requirements include the ability to carry a basic payload consisting of two twenty five cent coins.

There is no required textbook and instructors supply handout materials on topics covered both in the lecture and the laboratory.

VI. Identification and discussion of engineering competencies

Students are presented with the ratings about "best practices" for Mechanical Engineers to provide an idea of what potential employers seek in new ME graduates. The table is shown in the following page.

Industry's top twenty "best practices" for

Experienced ME's (left side) and New BS-level ME's (right side) ref. ASME.

Competencies	Scores	**Competencies**	Scores
1. Communication	98	Teams/Teamwork	94
2. Teams/Teamwork	98	Communication	89
3. Design for Manufacture	98	Design for Manufacture	88
4. Design for Reviews	97	CAD Systems	86
5. Design for Cost	97	Professional Ethics	85
6. Design for Performance	97	Creative Thinking	85
7. Design for Reliability	95	Design for Performance	85
8. Manufacturing Processes	94	Design for Reliability	82
9. Systems Perspective	92	Design for Safety	80
10. Concurrent Engineering	91	Concurrent Engineering	74
11. Creative Thinking	91	Sketching/Drawing*	74
12.*Project Management Tools	89	Design for Cost	74
13. Leadership*	89	Application of Statistics*	73
14. Design for Assembly	89	Reliability	73
15. Professional Ethics	88	Geometric Tolerancing*	71
16.*Design for Comn-Platf	88	Value Engineering*	70
17. Design for Safety	88	Design Reviews	68
18. CAD Systems	88	Manufacturing Processes	68
19. Product Testing*	88	Systems Perspective	67
20. Reliability	88	Design for Assembly	67

* Do not appear on both lists.

A glossary of terms is provided to the students to guide the discussion on the lists of desirable competencies. While there is no universal agreement on these criteria, it provides a starting point for students.

Most class sessions begin with a request from the instructors to the class to brief him on the subjects covered in the previous class. This review reinforces the repetition of knowledge acquired, promotes anticipatory behavior in students and at the same time the instructor can evaluate the level of comprehension.

The building of skills on students continues until just past mid semester. At that time, the teams are formed, the project (glider) has been defined and teams meet regularly to complete their project. The instructors become coaches and no formal lecture is given, instead the instructors will lecture on demand of the topics requested by the different teams.

The class does not culminate with the testing of the glider, the report and presentation by the teams of their effort, also there is a final examination. The final exam is a three hour test that consists on two parts. The first one is individual with questions regarding equations necessary for the design of the glider. The second part is a team effort project. For example: the teams can be given a set of rubber bands, clips, wooden chopsticks, pipe cleaners, straws and a block of wood of 1in. by 4 in. The teams are asked to build a catapult (not a slingshot) with the aforementioned elements. It is not required to use all the materiel. The task is to be accomplished in less than 40 minutes. The teams will discuss their approach to design, construction and testing of the catapult. The catapults are tested before the end of the three hour period. This final exercise allows students to practice basic critical thinking, selection of materials, design and assembly techniques, safety and reliability.

At the end of the term, students are given a self-assessment tool for them to evaluate how much progress they have achieved towards building up their engineering competencies as a result of the introductory class in mechanical engineering. (Appendix 3 – Assessment t-2)

The final technical report on their project is the beginning of their design portfolio.

VII. Conclusions

An introductory freshman course in mechanical engineering at Alabama A&M University was designed to become the starting point of incoming engineering students entering the Mechanical Engineering curriculum, with the purpose of building their engineering competencies. The course content and delivery methods have been revised each time it has been offered. The general response from the students to this course has been satisfactory and self-rewarding.
While is still early to assess a statistical metric to represent the impact on retention, it looks quite favorable judging from the reduced number of students changing majors or dropping from the class.

The first two graduates from the mechanical engineering program both have obtained manufacturing engineering positions with a significant responsibility in the production process in their respective companies. These results provide a source of confidence in the approach and techniques used in the development of ME 101 Introduction to mechanical engineering and the role it plays in the overall program.

Bibliography/References:

1. Taxonomy of Educational Objectives, Bloom et al.,Handbook 1. Cognitive domain, New York; David McKay Company, 1956.
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3. Integrating the Product Realization Process (PRP) into the Undergraduate Curriculum . The American Society of Mechanical Engineers, December 1995.
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5. BCAG Summer intern Training Program – Selected Airplane Design Exercises – The Boeing Company.
6. Basic Tools for Problem Solving and Design Teams - The Boeing Company.
7. Questions of Integrity – The Boeing Ethics Challenge – Edited by Nancy McCready Higgins, Director of Ethics and Business Conduct, The Boeing Company.

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Appendix 1. List of engineering competencies.

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.

Appendix 2. Course Content

Class Detailed Syllabi 50.min Period (1p) / Topic

1. Intro to modern engineering profile.(1p) - Industry perceived competency gaps – ASME/SME
2. Preliminary design of a pre-professional plan - identifying learning process SEA-ARK – understanding engineering requirements and goals. Stating Engineering problems (1p)
3. Tools for Problem Solving - The Team-work methodology -Decision Making- Brainstorming- Code of Cooperation- Experiment on 1-D communication (no visual contact) unilateral-communication consequences.
4. Intro to the Product Realization Process. (IPPD Process) – Structuring of a Story, Similarities between product manufacturing sequencing and a story; Bicycle drawing Example –individual (3 views) and Team Design Reviews.
   A two min. glider –(Lab session) – class discussion - Class exercise in basic design, construction and testing.
5. Project definition (A glider project)
   Product/process definition-Requirements: Performance, Safety, Manufacturability.
6. Paths to success. Understanding the Problem, (A good story teller), Early Planning, Understanding the Evaluation Metrics, (Good Reporting), Organization.
7. The business perspective, vision and the big picture. Learn What You Need to Know – Review of Performance Requirements for a Glider.
   (rate of descend, payload, weight determination by major components- statistical analysis of aircraft data 3p)
8. Basics of Glider Design - Aerodynamics – Forces in Equilibrium- Prototyping – Testing Evaluation – Fine Tuning –
9. Weigh Analysis - Market analysis for Materials.
10. Materials and Materials Selection - Examples and Practice - Boeing Selected Documents.
11. Learning Styles – Kolb – Team effects
12. Market outlook, market research. Importance of customer satisfaction. Example review The Commercial Satellite Market- US. Launchers cost per pound of payload.
13. The Bernoulli's Equation-Wind Tunnel – demonstration - Basic Wing section.
14. Calculation of Lift and Drag.. Equations, NASA airfoil data discussion.
15. Evaluating alternative materials / products
16. Teamwork practices - Planning Process; Basic resource analysis / allocation / lists /assignments to project members / resource cost reporting./
17. Time line practice - Resources and task scheduling. Mentor Evaluation. Practice (1p)
18. Conflict Resolution & Professional Ethics. Examples –Role Play –Selected Boeing Matl.
19. Production techniques – As per required - (2p)
20. Manufacturing, testing, and product evaluation. Glider Performance Test .(3 classes)
21. Final technical report - reviews-

Appendix 3.

M E Dept. Course Assessment Form # 002 (SAMPLE) Class:_____ Semester:_____ Year:_____

Referring to the list below: Please qualify by selecting numbers 5 to 1 in terms of class content/ Project relevance in assisting you to develop such competencies. (5-Highly relevant to 1-Not applicable)

Competencies	5	4	3	2	1	
1. Teams/Teamwork						
2. Communication						
3. Design for Manufacture						
4. CAD Systems						
5. Professional Ethics						
6. Creative Thinking						
7. Design for Performance						
8. Design for Reliability						
9. Design for Safety						
10.Concurrent Engineering						
11 Sketching/Drawing						
12 Design for Cost						
13 Application of Statistics						
14 Reliability						
15 Geometric Tolerancing						
16 Value Engineering						
17 Design Reviews						
18 Manufacturing Processes						
19 Systems Perspective						
20 Design for Assembly						
21 Design of Experiments						
22 Project Management Tools						
23 Design for Environment						
24 Solid Modeling/Rapid Prototyping Systems						
25 Design for Ergonomics (Human Factors)						
26 Finite Element Analysis						
27 Physical Testing						
28 Total Quality Management						
29 Design for Service/Repair						
30 Product Testing						
31 Process Improvement Tools						
32 Tools for "Customer Centered" Design						
33 Information Processing						
34 Leadership						
35 Statistical Process Control						
36 Test Equipment						
37 Industrial Design						
38 Design for Commonality-Platform						
39 Computer Integrated Manufacturing						
40 Design Standards (e.g. UL, ASME)						
41 Mechatronics (Mechanisms and Controls)						
42 Testing Standards (e.g. ASTM)						
43 Electro-mechanical Packaging						
44 Conflict Management						
45 Robotics and Automated Assembly						
46 Design for Dis-assembly						
47 Knowledge of the Product Realization Process						
48 Process Standards (e.g. ISO 9000)						