121st ASEE Annual Conference & Exposition
Indianapolis, IN
June 15-18, 2014
Paper ID #8411

Industry Based Senior Projects and the Four Pillars of Manufacturing Engineering

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Abstract

The Four Pillars of Manufacturing Engineering model focuses on the ties between academic programs and engineering practice. The pillars of the model focus on fundamental topic areas expected in any manufacturing program graduate. The foundation and lentil of the model address basic knowledge and competencies. The model is also recommended for other programs that are educating graduates who will serve industry. By addressing some or all of the Four Pillars model, programs will better prepare their students for professional practice.

The engineering program at Grand Valley State University (GVSU) has an interdisciplinary senior project program combining students in Computer, Electrical, Mechanical, and Product Design and Manufacturing Engineering. Companies submit project applications, normally involving product design, production equipment, and/or test equipment. The applications are vetted by faculty whom approve applications and assign project teams. Once approved, the teams do the design, build, and test work with funding from the sponsor. Faculty manage the academic aspects of the projects, while the sponsors approve technical work. Projects must satisfy faculty and sponsor for successful completion. As a result a majority of project outcomes are put into use in production, used in testing, or added to a company's product lineup. A number of the projects have resulted in patents. Industry focused projects have made graduates highly prized by employers, and the program well supported by industry.

The paper explores the relationship between the four pillars model and industry focused senior project. This will includes a sample project description and analysis.

The Capstone Senior Project Course

The final test of the student preparation is the senior project capstone course. This course uses many, but not all of the topics taught in prerequisite courses. In addition it introduces a few topics of a professional nature. The projects in this course are sponsored by local companies. Faculty vet the projects for suitability including technical challenge, well defined goals, and adequate financial support. The first segment of the project begins in the winter of the senior year. During this semester the students develop designs to satisfy the sponsor needs. The semester concludes with student presentations to sponsors. The sponsor must accept the proposal. In the second spring/summer semester the students order materials, build components, integrate components, test, and eventually deliver the result. Like the first semester, the sponsors must accept the final product for the course to conclude. The first semester includes lecture content, as listed[2]. The second semester of the course does not include lectures. Throughout both semesters, students hold weekly meetings with faculty and produce progress reports.

- An Overview of Design Products
- Needs Identification and Specifications
- Design Concepts and Embodiments
- People and Teams
- Decision Making
- Planning and Managing Projects
- Finance, Budgets, Purchasing, and Bidding
- Communication, Meetings, and Presentations
- Universal Design Topics
- Reliability and System Design

Given the key role of the capstone project course, the content is carefully chosen to ensure accreditation criteria and outcomes are addressed. As mentioned before, this does require some material that is not well suited to other classes, but well suited to industry sponsored projects. The four pillars of manufacturing model[1] represents a professional perspective on the outcomes from a manufacturing program. These group curriculum areas by industry needs, as illustrated in Figure 1. The capstone lecture content is highlighted in green as mapped to the four pillars. There is very little coverage of manufacturing topics, which is reasonable given the interdisciplinary course composition. However, there is a heavy focus on design, quality, and management as applied to all engineering disciplines. In all engineering programs at GVSU, the course serves as the designated source of business knowledge for many disciplines. For the manufacturing engineering students, most of the unhighlighted topics have been addressed in prerequisite courses.

The GVSU Senior Project Description

A senior project was conducted for a company that makes aftermarket equipment for personal watercraft. One of their product lines is a bilge pump that is manufactured in asia. After manufacturing the pumps are tested in asia, and then again upon arrival at the company. The current testing facilities were quickly built, had limited accuracy, and differed between the asian and domestic sites. The student project was to design and build two identical pump test stands that could be used in both locations. The stands were to provide a common testing standard. In addition the stands would allow the pumps to be connected quickly, and tested with minimal attention.

The machines measure flow rate for several different pumps with several different interfaces. During the tests these pumps run continuously for many hours while measuring the motor current draw. The tests stop after a designated time, or when a pump fails. After a test is complete the current and flow rate data is downloaded for analysis and record keeping. The two test stands were identical with the exception of the user interface. The asian version has the user interface translated to chinese, with the help of a faculty member.

The Lentil - Skill Sets Requested for Manufacturing Engineers

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 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

The Foundation - The Basics

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 1 - The Senior Project Lecture Content and the Four Pillars (highlighted in green)

The project was composed of a mixed group with five students from Mechanical, and one student from Product Design and Manufacturing Engineering. During the first semester the students developed specifications, conceptual designs, prototypes, detailed designs, budgets, and project plans for the sponsor. The project was reviewed critically and approved by the project sponsor for a budget of $13K. During the second semester the materials and components were purchased, built, assembled, and tested. During testing the students identified a number of design issues that were corrected, a normal occurrence for all projects. The final machine was presented to the sponsor for review later in the second semester. During the review they identified a number of small items requiring correction, also a normal occurrence. Once satisfied the customer signed for acceptance of the project, completing the student course work. The machines were then shipped to the domestic and asian locations and put into service.

During the two project semesters, the students met with the project sponsors and faculty managers on a weekly basis. They tracked their progress on shared spreadsheets, and used milestones to ensure progress. At the conclusion of the project the school displays projects to the general public. The poster the group produced can be seen in Figure 2. As expected, proprietary information is not shared, but there is plenty to show without it.

Figure 2 - Flow Test Project Poster

One of the final pump test stands is pictured in Figure 3 and 4. The major structural portions of the project were a welded iron frame and a stainless steel chamber. The iron frame was made at GVSU, but the stainless steel chamber was built outside by a supplier with the correct tools to cut and weld stainless steel. The students also fabricated a number of the smaller components such as fittings, latches, doors, handles, fixtures, etc. The controls for the machine were constructed with standard industrial control hardware. This included a PLC (Programmable Logic Controller), touchscreen HMI (Human Machine Interface), sensors, motor contactor, etc. The students built the controls cabinet and wrote the controls software.

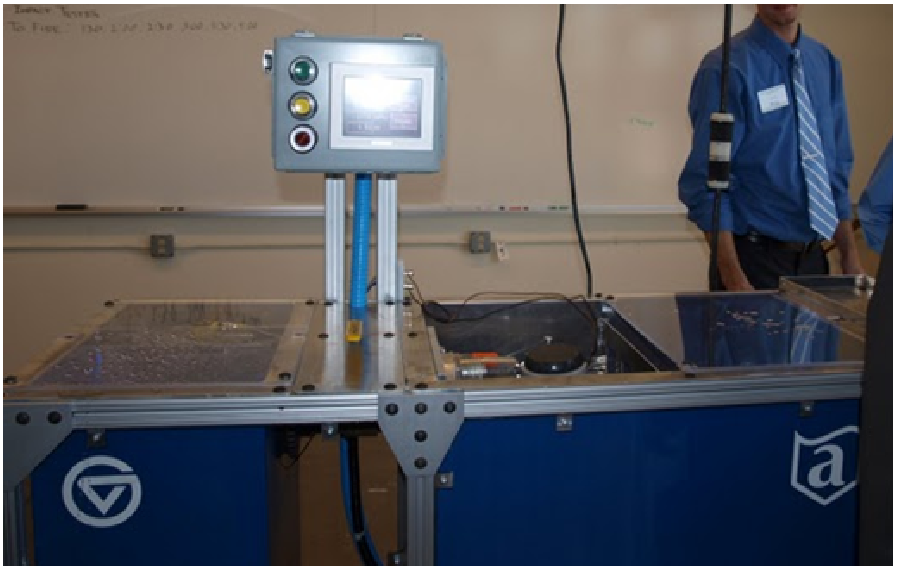

Figure 3 - The Test Stand with Touch Screen Interface

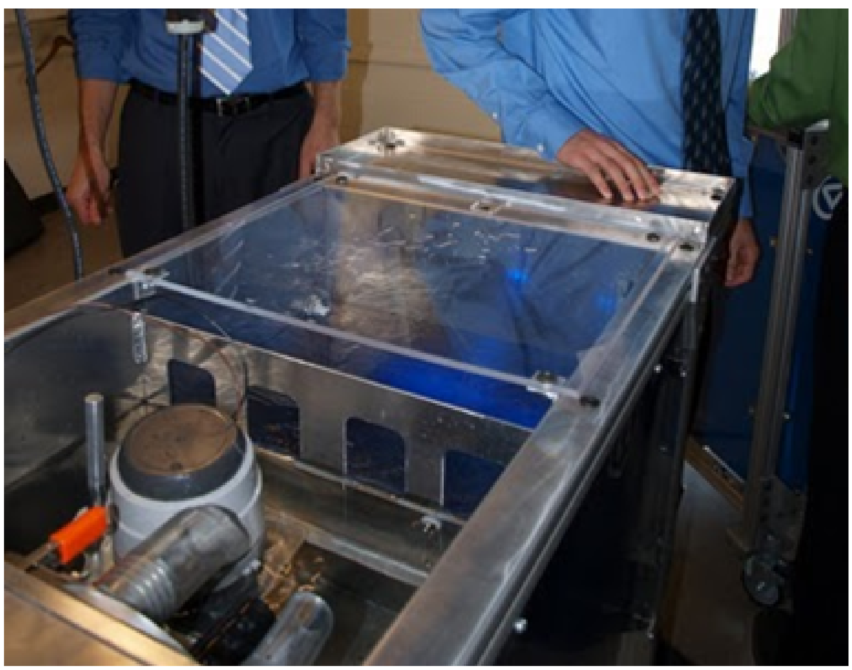

Figure 4 - A Pump is Mounted in the Test Stand

This project content spanned many aspects of the curriculum, as do all of the projects at GVSU. These are highlighted in yellow in Figure 5. The areas highlighted in the four pillars shows that the project covers all major subjects. This illustrates that students obtain a truly integrating experience in the project. Obviously this mapping will vary for any project. It is the role of the project selection process to find processes that span all of these columns for a broad experience. Although not used at GVSU, the other alternative is to select projects that permit a greater focus on fewer parts of the four pillars.

The Lentil

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 Core Areas

Materials and Manufacturing Processes

Engineering Sciences
- Statics and Dynamics
- Mechanics of Materials
- Fluid Mechanics
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- 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

The Foundation - The Basics

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 5 - The Four Pillars Content of the Pump Tester Project (highlighted in yellow)

Mapping ABET Criteria to the Four Pillars

The ABET criteria for manufacturing engineering programs are listed, with the l, m, n, and o criteria added for the program at GVSU. Some of these criteria are addressed extensively with the standard academic course work, for example a, b, c, e, g, and k. Other topics are more difficult to address in an engineering curriculum, for example d, f, h, i, and j.

A. an ability to apply knowledge of mathematics, science, and engineering,
B. an ability to design and conduct experiments, as well as to analyze and interpret data,
C. an ability to design a system, component, or process to meet desired needs,
D. an ability to function on multidisciplinary teams
E. an ability to identify, formulate, and solve engineering problems,
F. an understanding of professional and ethical responsibility,
G. an ability to communicate effectively,
H. the broad education necessary to understand the impact of engineering solutions in a global and societal context,
I. a recognition of the need for, and an ability to engage in life-long learning,
J. a knowledge of contemporary issues,
K. an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice,
L. materials and manufacturing processes,
M. process, assembly & product engineering,
N. manufacturing competitiveness,
O. manufacturing systems design, and manufacturing laboratory experience.

The ABET a-o criteria for GVSU are listed in Table 1, sorted by the Four Pillars topics they address. Anyone familiar with the accreditation process knows that there is variability in interpretation and implementation of these criteria. In this case the values in the table are relatively conservative listings for GVSU. Consider outcome *i) a recognition of the need for, and an ability to engage in lifelong learning*. This is called out in the foundation under personal effectiveness and in the pillar Manufacturing Competitiveness. One could argue that all of the core areas require an engineer to engage in lifelong learning in order to be effective. However, mapping the criteria may aid a program in creating surveys and similar tools for interfacing with industry that better addresses their concerns.

Table 1. Map of ABET Criteria to the Four Pillars of Manufacturing for the Senior Projects

Four Pillars Category	**ABET Outcome**
Professional Effectiveness	a, b, c, e, f, k, l, m, o
Materials and Manufacturing Processes	a, j, l
Product, Tooling and Assembly Engineering	a, b, c, e, f, j, k, m, o
Manufacturing Systems and Operations	a, c, g, h, j, k, l, m, o
Manufacturing Competitiveness	d,e,g,h,i,j,k,n
Mathematics and Science	a, b
Personal Effectiveness	d,e,i

Conclusions

Capstone projects are a valuable culmination for all engineering programs. They bring together previously disconnected course work into a professional framework to solve problems. Even though the project implementation varies between schools, the objectives are common. In this paper, the four pillars were used to describe the senior capstone project course at GVSU. The lecture content of the course was shown to wholly satisfy the management subject area, and provide strong coverage for the quality and design topic areas. An individual project was mapped against the four pillars, showing that the project provides a integrating knowledge for previous coursework.

Visual analysis using the four pillars model can be done very quickly, and provide an intuitive understanding of the role of a course or project in a manufacturing engineering curriculum.

References

1. Wikipedia, "Four Pillars of Manufacturing Engineering", http://en.wikipedia.org/wiki/Four_pillars_of_manufacturing_engineering
2. Jack, H., "Engineering Design, Planning, and Management", First Edition, Academic Press, 2013.