AC 2010-509: DESIGN EXPERIENCE IN A MANUFACTURING ENGINEERING PROGRAM

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Design Experience in a Manufacturing Engineering Program

Abstract:
Manufacturing engineering students develop skills for the various elements of the design process throughout the curriculum, culminating in a design implementation course during the senior year. Inspection of our curriculum shows that over 17 credit hours in the manufacturing engineering program involve engineering design components.

The program offers at least six courses in which engineering design is included. These courses are: Engineering Graphics, CAD/CAM, Manufacturing Automation, Simulation, Quality Control, and Manufacturing Design Implementation.

The sequence in product development starts with the geometric modeling utilizing 3-D solid modeling software. In this process, students use their knowledge and skills of solid modeling and assembly gained in the Engineering Graphics course, and product design and prototyping learned at the beginning of the CAD/CAM course to design and visualize their selected ideas. The projects are graded according to creativity, level of challenge, accuracy, quality of final product (prototype model), and peer presentation evaluation.

The Manufacturing Design Implementation is a three credit hours (one semester) capstone design experience taken in senior year where students integrate subject matter from their entire education background. Drawing on knowledge from different courses, students work in teams and are expected to make design decisions based on manufacturing requirements and realistic constraints such as material selection, functionality, cost, safety, and reliability. This paper emphasizes on the technical contents as well as educational outcomes of the design projects.

Introduction:

The Manufacturing Engineering (MANE) program at Virginia State University developed a curriculum that provides students with balanced coverage of different manufacturing engineering aspects as well as a strong university core requirement. The program focuses on the areas of automation, quality, manufacturing process, engineering analysis and design to prepare students for successful careers in manufacturing engineering and allied professions.

The curriculum consists of 63 credit hours of engineering fundamental and manufacturing core, 33 credit hours of mathematics and science and 31 credit hours of general education courses to prepare students for engineering practice as required by ABET [1] (Criterion 4) and to meet the University's general educational requirements as well.

The process of fourteen outcomes developed for the MANE program at Virginia State University along with the methodology of assessment was described [2]. The program provides students with extensive experience in basic science and mathematics, engineering science, laboratories, computers, design, communication and teamwork, along with humanities and social science. These experiences are carefully mixed through the entire curriculum to help students assimilate systematically the knowledge of scientific and technical principles to develop skills to compete in a global marketplace for engineering services.

The outcomes these courses and the objectives of the program are mapped as shown in Table 1.

Table 1- Mapping of Courses' Outcomes to Program Objectives

Institutial Mission

Program Objectives	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PO13	PO14
Objectiv 1	•	•	•		•							•	•	•
Objectiv 2	•	•	•		•			•			•			
Objectiv 3				•			•		•	•				
Objectiv 4			•			•				•				
Objectiv 5	•	•	•		•		•			•		•		

Curriculum

Courses	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PO13	PO14
ENGR 101	X	X			X		X				X			
ENGR 102	X	X			X		X				X		X	
ENGR 200			X				X				X			
ENGR 201					X									
ENGR 203					X						X			
ENGR 210	X				X									
ENGR 301		X			X								X	
ENGR 305	X				X							X		
ENGR 313	X				X									
ENGR 315	X				X									
ENGR 430								X		X			X	X
MANE 205	X			X	X		X					X		
MANE 210	X		X	X	X		X	X				X		
MANE 310			X				X				X			
MANE 315	X	X			X		X				X			
MANE 400	X				X	X	X		X					
MANE 410								X		X				
MANE 415				X						X				
MANE 420		X			X					X	X		X	
MANE 450		X	X	X	X		X				X			

Engineering Design Experience

MANE students develop skills for the various elements of the design process throughout the curriculum, culminating in a design implementation course during the senior year. The program offers at least six courses in which engineering design is included. These courses are:

- ENGR 200-Engineering Graphics,
- MANE 310-CAD/CAM,
- MANE 315-Manufacturing Automation,
- MANE 420-Simulation,
- ENGR 430-Quality Control, and
- MANE 450-Manufacturing Design Implementation.

These six major courses and some other courses distributed throughout the curriculum include elements of design that adequately defines an integrated design experience for students in the manufacturing engineering program. During the senior year, students also may gain additional design experience in their chosen ENGR/MANE elective courses such as Senior Project (MANE 461) and Special Topics (MANE 499). Most of these courses are lab included and students are assigned to work on design projects to satisfy the following program outcomes.

PO2. Ability to perform engineering analysis by designing and conducting appropriate experiments and analyzing and interpreting results.
PO3. Ability to design products, equipment, tooling and environment for manufacturing systems.
PO5. Ability to identify, formulate, and solve engineering problems.
PO7. Ability to communicate effectively.
PO8. Ability to implement technology with an awareness of important social issues and understand the impact of engineering solution in a global and societal context.
PO10. Knowledge of contemporary issues such as understanding the creation of competitive advantage through manufacturing planning, strategy, and control.
PO11. Ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

Laboratory Experience

A comprehensive laboratory experience is a fundamental component of the manufacturing engineering curriculum. In line with the current trends in manufacturing engineering practice, the students are involved in computer-based as well as physical experimental work related to both the basic sciences and manufacturing engineering topics. All Courses listed in Table 2 include hands-on laboratory component related to the topics covered. The list includes the approximate percentage of lecture and lab in each course.

Table 2- Hands on Laboratories

Lab. included courses	Credits	Contact Hours	Lecture	Lab.
ENGR 101 Intro. to Engineering I	2	4	50%	50%
ENGR 101 Intro. to Engineering II	2	4	50%	50%
ENGR 200 Graphics	2	4	50%	50%
ENGR 430 Quality Control	3	3	75%	25%
MANE 310 CAD/CAM	3	5	50%	50%
MANE 315 Mfg. Automation	3	4	70%	30%
MANE 450 Mfg. Design Implement	3	5	25%	75%

Senior Capstone Experience

The MANE 450-Manufacturing Design Implementation is a three credit hours (one semester) capstone design experience taken in senior year. This course provides extensive experience in manufacturing design and implementation. Drawing on knowledge from different courses, students work in teams and are expected to make design decisions based on manufacturing

requirements and realistic constraints such as material selection, functionality, cost, safety, and reliability. At the end of the course, student groups are required to demonstrate their design through a final formal presentation to the faculty, fellow students, peers and a jury of industry guests and faculty from other departments. Students also write a detailed design report as part of the course requirements.
Students are assigned to select a project in the area of (a) Manufacturing Process System Design or (b) Product Design.

The scope of the work in format (a) may be summarized as follows:

1. Design a simple product using available resources of our CIM facility.
2. Design and develop an automated manufacturing process using CIM facility.
3. Implement, debug, test the system, and run production with minimal human intervention.
4. Include process monitoring, error recovery, and cycle time.

This format was first practiced in the Spring of 2005. Students implemented a Computer Integrated Manufacturing of a Desktop Card Holder. Second time, this format was practiced in Fall 2006. The project for this year was "Computer Integrated Manufacturing of a Desktop Cannon." [3]
In format (b), the students complete a comprehensive design project which includes design and fabricating of a marketable product. The product should be commercially desirable and be producible within the semester using our laboratory facilities. This format was first practiced in the Spring 2007. The project was design and development of a "Microprocessors Trainer" to be utilized by electronics engineering technology and computer engineering students.

Case Study Project

A great example of design experience in our Manufacturing Engineering program is a project for Spring 2008. The purpose of the project was to design and fabricate a mini desktop 3-axes CNC machine. The following outlines the objectives and the various phases within the project:

Objectives:

1. Design, Manufacture and Test of a desktop 3-axes CNC (Computer Numerical Control) machine that:
   - reads instructions from a personal computer
   - performs tasks such as plotting, milling, spot drilling and engraving
   - be durable and upgradeable
   - be user friendly
   - be safe and operable by entry-level engineering students
2. Understand Constraints (Time, Budget, Equipment limitations, Size and Material)
3. Learn to work in a given time frame
4. Learn to work in a team environment

Project flow:

PHASE I: Project Planning

- *Brainstorm Ideas*

- *Introduced to idea of CNC*
- *Independent Research, Meeting, Decision….*

PHASE II: Concept and Detail Design

- *3-D Modeling of Design Alternatives*
- *Parts and Assembly Design*
- *Detail Design*

PHASE III: Implementation

- *Purchase / make machine components*
- *Assembly*
- *Test & Troubleshoot*

A team of 4 students successfully completed the project and were able to demonstrate the designed and fabricated machine operation in presentation day. The following aspects of the project were highlighted in the presentation:

a) Brief Overview of the Project

- Project Planning
    - Define Work Breakdown Structure (WBS)
    - Develop Responsibility Assignment Matrix (RAM)
    - Determine resources and constraints
- Methodology during implementation
- Design Alternatives
- Benefits of Team and Project

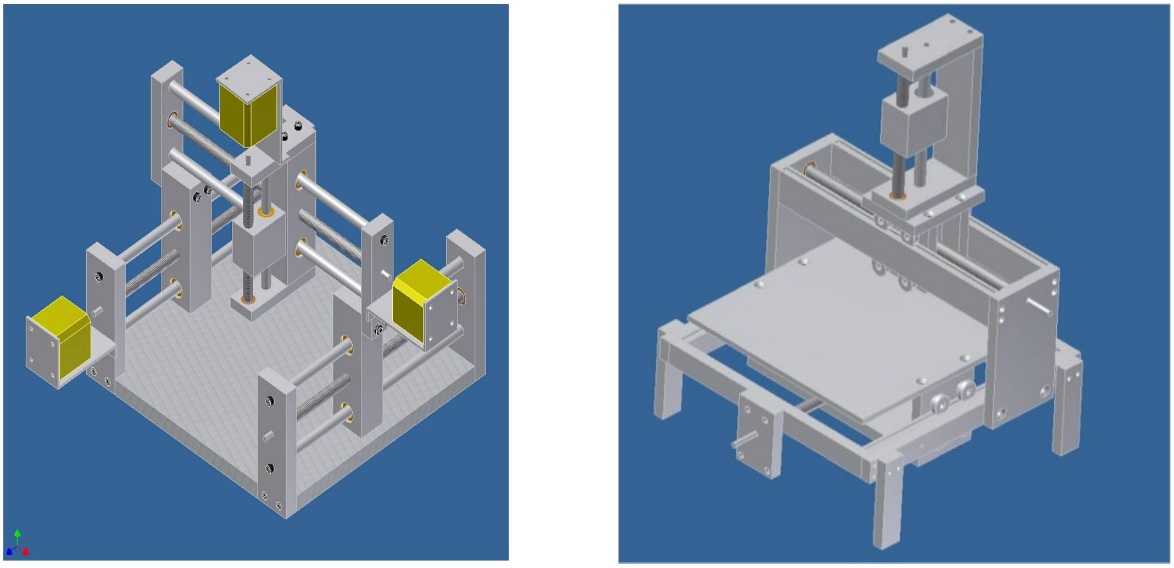
b) Results of the project

- Challenging but successful project
- Working prototype at nominal cost of $500
    - Market feasibility
    - Cost effectors: drive system, structural design and material
    - Accuracy: yet to be determined
- Enhanced team-working and time management skills
- Further development of acquired engineering skills and knowledge

c) Conclusions and Future Work

- Successful and functional product within limited time and limited budget
- Enhance design for manufacturing a real working product
- Upgrade to a 5-axes design
- Integrate with a desktop robotic arm to practice flexible manufacturing system design

The sequence for the design of the product started with sketching or geometric modeling utilizing solid modeling software. In this process, students used their knowledge and skills of solid modeling and assembly to visualize their design alternatives shown in Figure 1.



(a) (b)

Figure 1- Design alternatives

After a design review, the team decided to proceed with alternative (b) and came up with the Work Breakdown Structure (WBS) shown in Figure 2.

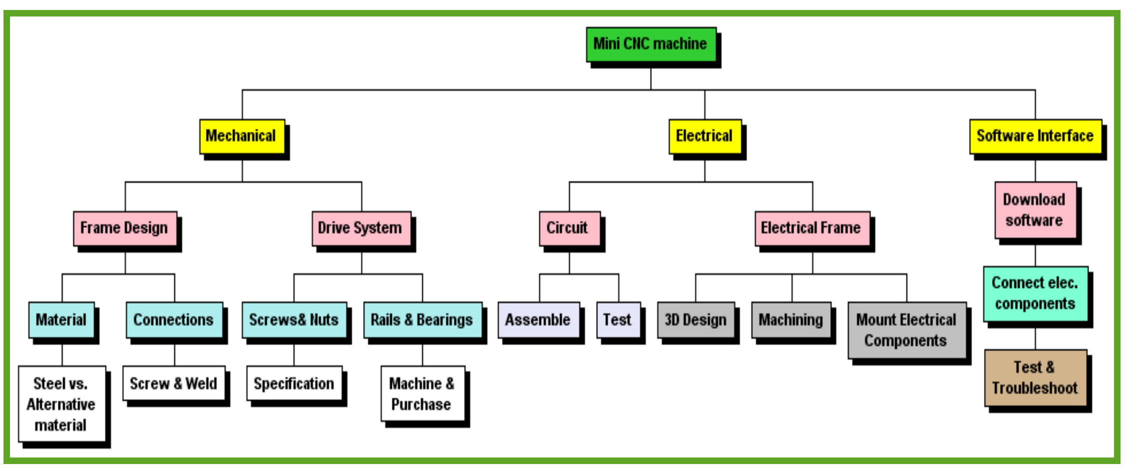


Figure 2- Work Breakdown Structure (WBS) of the project

Following the concept and detail design process and defining the fabrication specifications, the team worked on implementation stage to build the structure and order the required parts. The purchased parts list and the assembly drawing of the selected design are shown in Figure 3 and Table 3 respectively.

Table 3- Purchased Mechanical and Electronic Parts

	Part Description	Part Number	Quantity	Unit Price	Line Price
1	Lot of 8 Shielded Extended Bearing 1/4"x22x7	Kit1080	2	$4.95	$9.90
2	Acme Lead Screw, 1/2 - 10, RH, Steel (8 in.)	59284	1	$6.35	$6.35
3	Acme Lead Screw, 1/2 - 10, RH, Steel (14 in.)	59284	2	$9.53	$19.06
4	Acme Sleeve Nut, 1/2-10, RH, Bronze	89403	1	$15.01	$15.01
5	Acme Threaded Mount Nut, 1/2-10, RH, Bronze	90222	2	$16.45	$32.90
6	Materials for Structure *			$30.00	$30.00
	Sub-Total for mechanical parts				**$113.22**

1	Green Monster 400 OzIn 8-Wire Stepper Motor	HT23-400	3	$69.95	$209.85
2	Power Supply	FS-20024-1	1	$39.95	$39.95
3	Stepper Motor Driver	SideStep	3	$35.95	$107.85
4	RF Isolated CNC Breakout Board	PBX-RF	1	$45.99	$45.99
5	10PIN 4" IDC Cable		3	$10.00	$30.00
6	Cables and Wires *			$25.00	$25.00
	Sub-Total for electronic parts				**$458.64**

* Price is estimated (The item was available inhouse inventory)

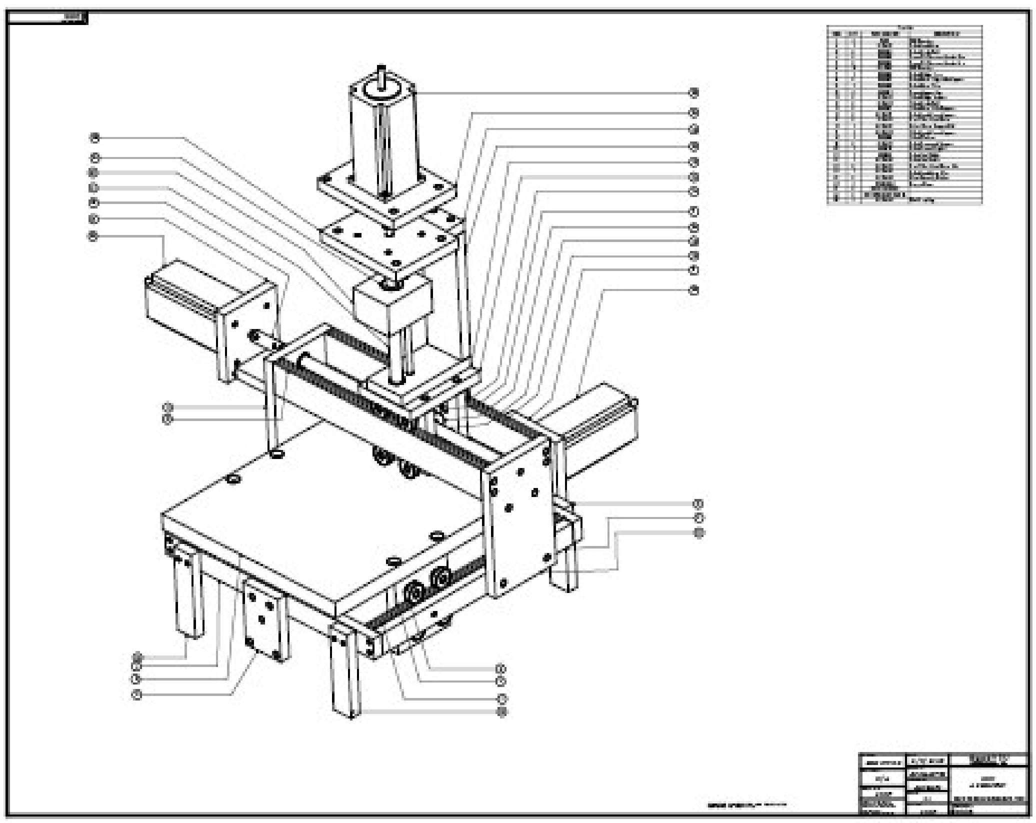


Figure 3-Assembly drawing and attached Bill of Materials

The project was built and assembled by students with minimum supervision in our machine shop. In addition to hand tools, band saw, lathe, and mill; CNC machine center was used to make the parts. A free trial version of Mach3 (CAM software) downloaded from internet was used in this project. The virtual panel of the Mach3 and stepper motors wiring for test are show in Figures 4 and 5 respectively.

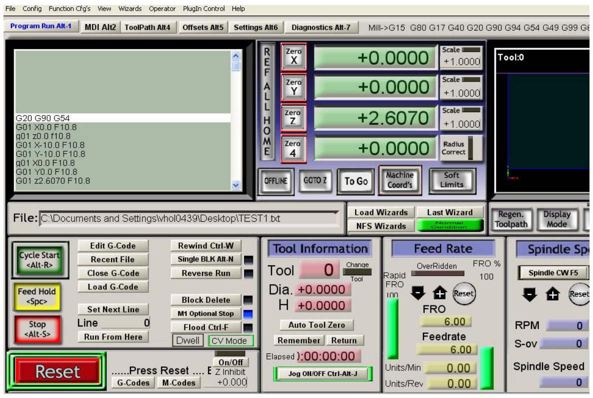


Figure 4- Mach3 program panel

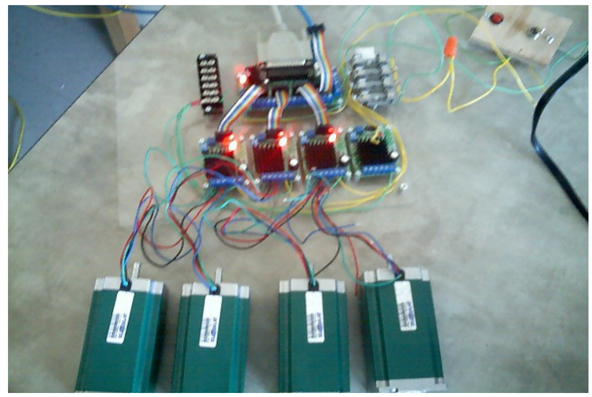


Figure 5- Stepper motors wiring and test

By receiving the purchased items and building the parts machine was successfully built and tested before the semester ended. The solid model and the fabricated final product are shown in Figures 6 and 7 respectively.

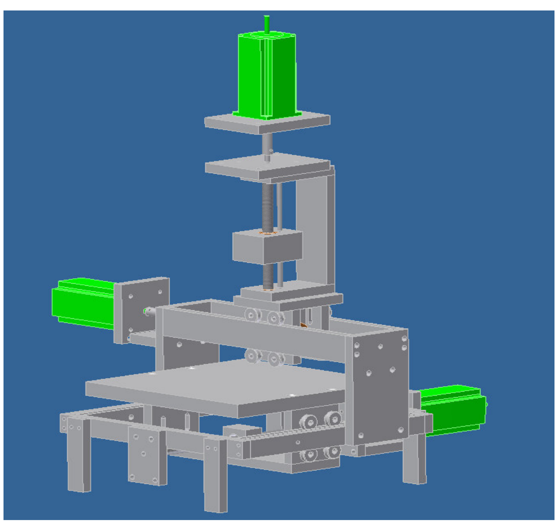


Figure 6- Solid model of final product

Figure 7-Fabricated final product

Capstone Course Outcome Assessment

In both formats, the projects were done in teams of no more than five students. In all cases, the teams presented their final design to faculty and industrial advisory committee members and the fellow students at the end of the semester (presentation day). The team works were evaluated by a jury of faculty and industry members. At least five reviewers (four Manufacturing Engineering faculty, and one from Industry Advisory Committee) have assessed the outcomes of the course using rubrics related to oral presentation and final project report. The result of the outcome assessment of the capstone design experiment is shown in Table 4.

Table 4- MANE 450 Course Outcomes Assessment Results (Spring 2008)

	Assessor 1	Assessor 2	Assessor 3	Assessor 4	Assessor 5	Average	Percent for 3	Percent for 4	Percent for 5
Program Outcome 2:							**13%**	**67%**	**20%**
Developing experimental goals and procedures	4	3	4	4	5	4	20%	60%	20%
Use and operation of laboratory facilities	5	3	4	4	5	4.2	20%	40%	40%
Formulate and present experimental results	4	4	4	4	4	4	0%	100%	0%
Program Outcome 3:							**10%**	**20%**	**70%**
Identifying design goals and constraints	5	4	5	4	5	4.6	0%	40%	60%
Reasoning and preparing a design solution	5	3	5	5	5	4.6	20%	0%	80%
Exploring alternative design options	5	3	5	5	5	4.6	20%	0%	80%
Select and use appropriate tools in design process	5	4	5	5	4	4.6	0%	40%	60%
Program Outcome 4:							**20%**	**80%**	**0%**
Effective teamwork in oral presentation	3	3	5	5	5	4.2	20%	80%	0%
Program Outcome 5:							**20%**	**47%**	**33%**
Engineering knowledge of subject area	4	3	5	4	5	4.2	20%	40%	40%
Engineering analysis & judgment	4	3	4	4	5	4	20%	60%	20%
Identifying, formulating and solving engineering problems	4	3	5	4	5	4.2	20%	40%	40%
Program Outcome 7:							**7%**	**20%**	**73%**
Presentation (organized, focused and interesting)	5	3	5	5	5	4.6	20%	0%	80%
Presentation (engagement, language, visual aids)	5	4	5	4	5	4.6	0%	40%	60%
Presentation (consistent, professional and respectful response)	5	4	5	5	5	4.8	0%	20%	80%
Program Outcome 11:							**13%**	**47%**	**40%**
Selection of analytic and design tools for an engineering problem	5	4	5	5	4	4.6	0%	40%	60%
Practical and analytic techniques in solving engineering problems	5	3	4	5	5	4.4	20%	20%	60%
Knowledge of using engineering approaches to problems	3	4	4	4	4	3.8	20%	80%	0%

Lesson learned in Case Study Project

At the initial steps, the students found the project to be intimidating and challenging. However, as the team became more engaged in the project, these challenges were met through the practice of the different aspects of engineering and design. As a result, a complete and functional product was built and presented at the end of the semester. The lessons learned in this project are:

- It was easy to come up with a conceptual design
- The process of actually building the designed product is a critical
- Improved understanding of engineering science knowledge
- Increase students non-technical skills such as teamwork and communication
- Increase students motivation
- Increase students design skills
- During construction, students learn the importance of
    - tolerances in assembly process
    - material selection
    - alignment procedure
    - fasteners and joining methods
    - decisions on make or buy of components

Conclusion

Manufacturing engineering students develop skills for the various elements of the design process throughout the curriculum, culminating in a design implementation course during the senior year. The Manufacturing Design Implementation is a three credit hours (one semester) capstone design experience, where students integrate subject matter from their entire education background. As discussed in the case study, a team of 4 students designed and built a functional mini-desktop CNC machine. The assessment of the Capstone design experiment indicated that the six program outcomes achieved levels of 80 to 93%.

References:

1. “ABET Criteria for Accrediting Engineering Programs”, Effective for Evaluations During the 2007-2008 Accreditation Cycle. WWW.ABET.org
2. J. Ansari, A. Javaheri, S. Tompkins, K. Williamson, “OUTCOME ASSESSMENT PROCESS IN A MANUFACTURING ENGINEERING PROGRAM”, *Proceedings of the 2008 ASEE Annual Conference and Exposition*.
3. J. Ansari, A. Javaheri, N. Ghariban, “CIM LAB TO SUPPORT MANUFACTURING DESIGN IMPLEMENTATION”, *Proceedings of the 2007 ASEE Annual Conference and Exposition*.