

**AC 2007-702: A MANUFACTURING ENGINEERING CAPSTONE DESIGN  
COURSE: MOVING WITH THE REAL WORLD**

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## **Manufacturing engineering capstone design course: Moving with the real world**

### **Abstract**

A capstone course in manufacturing engineering has been offered to undergraduates majoring in manufacturing engineering at Texas State University for four years. In this course students experience all aspects of the design/development cycle: product design, prototyping/verification, manufacturability analysis, and the manufacturing design of the product. This course has been continuously updated to offer the latest tools, software, and teaching and evaluation techniques. Students are assigned to teams based on their learning style, technical and academic background, and schedule. Students must complete an industry-supported project. In this course, students are evaluated both individually through performance on homework, quizzes, and exams; and also as team members on the basis of a design and prototype review, final report, presentation, peer evaluation, and comments by a panel of experts. Course assessment is based upon a variety of surveys and feedback mechanisms. This paper describes several of this year's projects. The overall conclusion, on the basis of these projects, is that the outcome of this course has been satisfactory in all aspects. This success is due to appropriate project, sponsor support, students' efforts, faculty performance, departmental support, and the feedback from the panel of experts.

### **1- Introduction**

In recent years, owing to the World Trade Organization (WTO) agreements and business globalization, a new era of global trade has emerged. Industries today have to compete not only with local and regional rivals but also with competitors from all over the world. Global competition has created major challenges and opportunities for industries. On the one hand, many previously unknown and nonexistent companies now offer goods and services of competitive quality and price, on the other, a huge global market is now available to companies. The keys to success in this competitive environment are high product quality, low cost, and rapid response to customers' needs. This new condition has considerably affected the United States manufacturing sector. Total employment in manufacturing in the United States declined from 17 million workers in 2000 to 14.2 million in 2005 [1]. According to Bivens et al., three main factors are responsible for the problems in the US manufacturing sector:

A- Overvalued US dollar and the large trade deficit: The overvalued dollar combined with the trade agreements that "included investment provisions to ease relocating production facilities abroad," was a major factor in manufacturing firms' decision to outsource their jobs out of the United States, and especially to China.

B- Retiree health and pension costs are a burden on US firms: Large job losses in manufacturing sector in recent years have led many eligible workers to retire early. This, combined with high pension and health benefits for retirees (compared to those of retirees in other sectors) is putting more pressure on US firms.

C- The shortage of workers with skills needed in the US manufacturing: Bivens et al. reported that a survey conducted by the National Association of Manufacturers ([www.nam.org](http://www.nam.org)) and Grant Thornton, LLP in 1997 showed that 88% of American manufacturing firms suffer from a shortage of qualified workers. In addition, the skills requirements for workers have significantly increased for all manufacturing industries, "from the most labor-intensive (apparel) to the most technology-intensive (medical instruments manufacturing)" [2]. While the first two factors, in

Bivens' view, are related to macro scale decision making at the government level, academic and educational institutions are the major players in the third factor (shortage of skilled workers).

The study by the Society of Manufacturing Engineers (SME) identified communication skills, teamwork, project management, business skills, and life-long learning as some key competency gaps in recently graduated engineers [3]. Also, Accreditation Board for Engineering and Technology (ABET) criteria [4] maintain that "students must be prepared for engineering practice through the curriculum culminating in a major design experience based on the knowledge and skills acquired in earlier course work and incorporating engineering standards and realistic constraints that include most of the following considerations: economic, environmental, sustainability, manufacturability, ethical, health and safety, social, and political." While most SME's gaps and ABET's engineering practice criteria can and must be assimilated throughout the four-year curriculum, the capstone senior design course provides the most appropriate framework for simultaneously addressing practically all of the gaps and criteria.

The undergraduate program in manufacturing engineering at Texas State University was started in 2000 and its first group of students graduated in 2003. Even though this program started in one of the most difficult times for the manufacturing sector in the US, our graduates compete with many highly experienced job seekers and almost all new graduates have accepted positions relevant to their major, some in prestigious companies such as Boeing, Toyota, and Applied Materials. This is mainly because these students have been trained as multi-expertise engineers. In this department, course materials are continuously updated based on feedback from Manufacturing Engineering Advisory Committees and the latest available tools and techniques are available to offer the most relevant and timely topics in the real world business. In addition, our new graduates have benefited from the fact that the recovery of the manufacturing sector in Texas has started sooner and exceeded than the nation average. In 2005, "Texas added roughly 7,500 manufacturing jobs, a 0.8 percent increase, compared with a U.S. loss of 72,500 jobs, a 0.5 percent decline" [5].

The goal for the capstone design course in manufacturing engineering program at Texas State University was to provide teams of students the opportunity to work with open-ended design problems wherein most aspects of the product development cycle, including product design, prototyping/verification, manufacturability analysis, and business plan of the product were experienced [6]. The course first offered in the fall semester of 2003 and since then it has been continuously updated, adjusted, and modified based on feedback and surveys' results, industries' needs, and new tools and techniques. The projects that were undertaken by the most recent class (2006) were fully sponsored by industry.

In this paper major activities and milestones in the senior capstone design course taught in Fall 2006 are explained. The rest of this paper is organized as follows. In Section 2, lectures and projects activities and milestones are presented. Section 3 gives a detailed description of course assessment. In Section 4, sample projects are explained. Finally, conclusions are given in Section 5.

## 2- Activities and Milestones

Preparation for this course usually starts months before the semester begins and continues weeks after the end of the semester for the course outcome analysis. Major activities and milestones for this course are as follows.

### 2-1- Pre semester activities

One of the most difficult tasks in teaching this course is finding interested industrial sponsors with appropriate projects (area, scale, complexity, deadline, failure risk-ability, etc.). The sponsor search was limited to local small or midsize manufacturers within a 30-mile radius of the campus. Contacts start two or three months before the fall semester through emails, letters, phone calls, and personal connections through interns, alumni, colleagues, employed students or their parents, and friends. When planning the 2006 projects, these contacts were the most productive. One of our new graduates employed in a pre-manufactured home construction plant facilitated the cooperation between the university and that plant, which was about 15 miles away. The result was that this new plant that built energy-efficient homes sponsored all students with real world projects in tools design and automation to improve their productivity. This industry sponsor provided two pages of text and two hours of video describing all specifications and requirements for six projects to be chosen by the students. The main purpose was to make sure that students fully understood the process and the project from the outset.

### 2-2- At the beginning of the semester

Teams of four students are formed within the first three weeks of semester. In the first session, students learned about the available projects through descriptions and videos; a plant visit followed in the second week. To create healthy competition among teams and to ensure high-quality projects, teams were set up according to the characteristics of the members. Using the students' academic record, teams' average grade point average (GPA) were equal or very close. Also, an online questionnaire, developed by Richard Felder and Barbara Soloman at North Carolina State University, was used to evaluate students' learning style and strategies [7]. On this questionnaire, a person's learning style, such as active and reflective, sensing and intuitive, visual and verbal, and sequential and global are evaluated by 43 multiple-choice questions. We tried to strike a balance of sequential and global learners on each team. "Sequential learners tend to follow logical stepwise paths in finding solutions; global learners may be able to solve complex problems quickly or put things together in novel ways once they have grasped the big picture, but they may have difficulty explaining how they did it." [8] In addition, other aspects of the results of this questionnaire were used during the semester. For example, we found that almost all of the students in the class were visual learners therefore, course materials and lectures were supplemented with additional pictures, graphs, and videos.

These two factors--GPA and learning styles--were combined with other factors collected from students, such as students' expertise, and work and/or software experience, schedule, project preference, and teammate preference, to create well-balanced teams.

In addition, all students took a theory and practice safety class to familiarize themselves with safety procedures and the potential risks they would face in a workshop.

### 2-3- During the semester

Since this course is offered to senior students, they were assumed to have had most of the background, i.e. in materials, design, manufacturing, quality, engineering economics, and

“hands-on” fabrication skills, prior to taking this course. However, a review of some of the topics that are crucial for conducting a successful project, were presented. Course topics include concurrent engineering concepts, identifying customer needs, innovation and creativity, team work and project management, defining product specifications and quality function deployment (QFD), concept generation and selection, design, design for manufacturing and assembly, robust design and design of experiments (DOE), rapid prototyping, failure mode and effects analysis (FMEA), and business plan. The third edition of *Product Design and Development* by Ulrich and Eppinger was used as the course textbook [9] while some supplementary materials were added to lectures.

In addition to the regular three-hour lecture class on Wednesdays, students and faculty were available on Fridays for project-related activities. These activities included weekly homework (a team-based assignment that was in fact a piece of the final project), plant visit, meeting with sponsor, and/or work in computer labs or workshops. The project sponsor was also available, either at the university or at the plant to meet with faculty and students almost every week for clarifying the problem, giving feedback, testing an idea, or authorizing the purchase of expensive equipment. The number of plant visits was increased to two to three per week in the final three weeks of the semester when students started their final assembly, installation, and testing.

#### 2-4- At the end of the semester

In addition to conventional evaluation methods such as a final exam, students needed to demonstrate and test their final prototypes two to three weeks before the end of the semester. This took place as the prototype was functioning and being tested in its real industrial condition. Any deficiency or problem in the prototype needed to be fixed before the final presentation day. Also, each team submitted a 15-page report describing the entire project.

In order to stimulate a healthy competition among the student teams, a "best product development" contest was held at the conclusion of the projects. A panel of experts ranked student teams based on the quality of their project and their 12 minutes oral presentations. The panel of experts included the class instructor, other faculty, members of the Manufacturing Engineering Program Advisory Committee, industrial guests (alumni and previous winners), sponsors, potential sponsors, the department chair, and the dean of the college. The best team received a best team certificate and cash prize offered by the sponsor.

#### 2-5- Post semester activities

After submitting the students' final grades, the students' performance and comments, and the panel of experts' views that were collected from the different surveys are summarized, analyzed, and considered for the future projects. Section 3 (course assessment) explains the methods that were used to collect and measure comments, views, and students' performance. Appendix A explains the statistical results of the student assessment surveys.

#### 3- Course assessment

A Multi-criterion approach was used to make sure that students have met the course and program objectives and the ABET criteria. In this approach, data collected from several sources were reviewed and analyzed.

### 3-1- Students

Pre and post semester survey: To evaluate learning experiences of the students, a formal course evaluation was designed by an external source, Keith Research and Evaluation, a private educational testing firm based in Austin, Texas. This evaluation consisted of quantitative and qualitative parts and was conducted in two steps. In Step 1, students were asked six quantitative questions with possible answers between 0-10 (0 for “not at all successful” and 10 for “extremely successful”). These questions rated their knowledge at the beginning of semester. Additionally, some qualitative questions were asked. These questions were graded by using the evaluator’s template and an established scale. These responses established the quantitative baseline of students’ knowledge at the beginning of the course. Step 2 took place at the conclusion of the semester. Students were asked the same questions as in Step 1. The questions dealt with topics such as their understanding product and process development, design for manufacturing and assembly, writing, presentation, and project management skills. In both steps a numeric ID was assigned to each student. Therefore, both surveys were anonymously studied together.

ABET survey: As part of the requirement for the manufacturing engineering program accreditation two assessment forms are filled at the end of the semester. The first assessment form is a summary of students’ responses to an anonymous survey in which students rate their knowledge on 10 major topics of the course. The summary will illustrate students’ strengths and weaknesses. The second assessment form is filled out by the course instructor, who evaluates class grade average and standard deviation for each major topic in the course. Each grade average is a weighted-based score from homework, quiz, and grades on exam questions that are related to the topic.

Peer evaluation: One of the objectives of a project-based course is that students experience team work, take responsibility, and exercise project management tasks. To obtain a better understanding of each student’s performance as a team member, students evaluated and rated themselves and their teammates on different aspects of a team in the form of rank-based and descriptive feedback. This is confidential survey is available only to the course instructor. As default, all students within a team receive the same grade for the project. The only exception is in the case of unusual problems or misconduct by a student that is mentioned by all other team members in the peer evaluation form.

Faculty evaluation: Similar to any other course, students evaluated the course and the instructor in the final week of classes. This confidential and anonymous evaluation included two parts: multiple-choice questions and descriptive feedback.

### 3-2- Faculty

In addition to other assessment methods, the class instructor evaluated each student individually and the entire class as whole, to make sure that ABET criteria were met. This evaluation included the weekly homework, weekly quiz, weekly project progress and presentation; final project prototype, report, and presentation, and the final exam.

### 3-3- Panel of experts

The panel of experts was present for the final project presentation/competition. They expressed their views and feedback on individual projects and on the entire class by completing two forms. The first form was the competition form on which each panel member ranked teams based on the quality of the project and commented on the strengths and weaknesses of each team. In addition, each panel member filled out an ABET form that evaluated the performance of the entire class.

### 3-4- Sponsor

Projects' sponsor actively participated on the panel of experts and returned similar feedback as other panel members. In addition, our sponsor met with the teams on a weekly basis. They offered feedback to teams on any occasions. In addition, they reacted to projects in other ways as well. For example, based on the original agreement, the sponsor agreed to pay \$100 to each student on the best team. At the end of the presentation, they extended this reward to all students. In addition, the sponsor offered employment to some students and showed their ongoing interest by signing another contract for new projects with the university for the coming semester.

### 3-5- Course assessment summary

The conclusion of the course assessment, for both quantitative and qualitative methods, shows that this course has met its designed objectives. Pre- and post-semester technical surveys show that students' knowledge and proficiency have improved in all 12 designated areas. The results of these surveys are shown in Appendix A. Also, students' responses to the instructor evaluation survey were very favorable. They think that this course has succeeded in creating a senior-level student culture that values problem- solving skills, understands the complexities of work in the field, and has an appreciation of the course that they have completed. Students' anonymous comments about this course can be viewed on the instructor webpage [10]. In addition, the ABET assessment, based on class performance on homework, quizzes, and exams show satisfactory results for all course topics (Table I). Also, comments from panel of experts and the project sponsor were very positive and satisfactory.

Table I- ABET assessment based on class performance

Measure\topic	Understand concurrent Engineering concept	Design parts and assembly with a CAD software	Generate concepts and developing the best concept for the product	Apply design for manufacturing and assembly rules on designs	Completing and working with Failure Mode and Effects Analysis (FMEA) chart	Understand robust design and design of experiment (DOE) concept	Understand team working and managing team	Understand business plan and cost estimation
Max	10.00	7.00	10.00	10.00	10.00	10.00	10.00	10.00
Ave	8.83	6.60	9.09	8.56	9.43	9.20	9.20	9.33
Sigma	0.92	0.83	1.05	1.18	0.95	0.62	0.90	2.58
%Ave	0.88	0.66	0.91	0.86	0.94	0.92	0.92	0.93

#### 4- Sample projects

Four projects were conducted in the senior design course in the Fall 2006 semester. They all were related to spline and structural insulated panel (SIP) production lines and to roof panel installation mechanisms.

##### 4-1- OSB tilt and transfer cart

In this project, student designed and prototyped two full-scale cart systems that are able to move and rotate a batch of Oriented Strand Board (OSB) easily. OSB length varies from 4' to 24' and the width varies from 2' to 4' but will typically be 4'. The whole batch weight can be up to 1500 lb. This cart system is design for a hydraulic tilt mechanism; however, the rotation mechanism was successfully tested by use of a forklift.

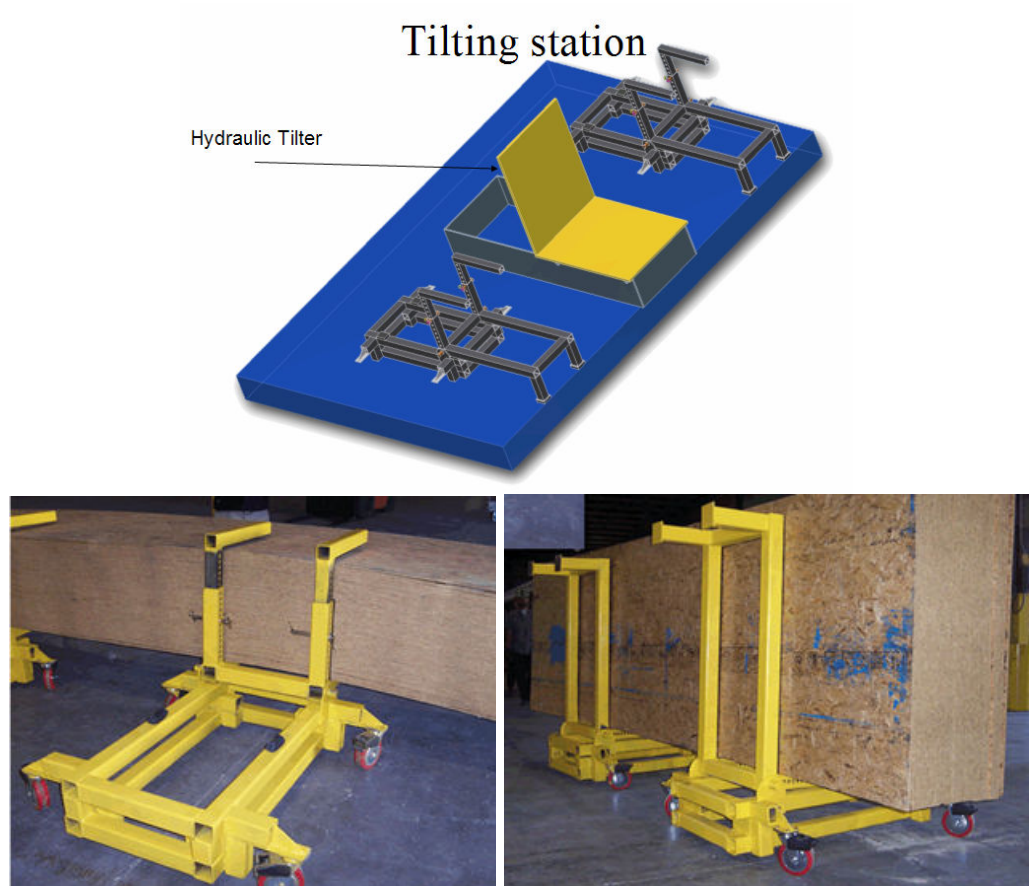


Figure 1. OSB tilt and transfer cart



#### 4-2- OSB placement mechanism

In this project, a portable crane and adjustable clamping mechanism that is able to take OSB sheets and place them either-side up on a stack of alternating OSB and Polystyrene foam with exact placement was designed and prototyped.

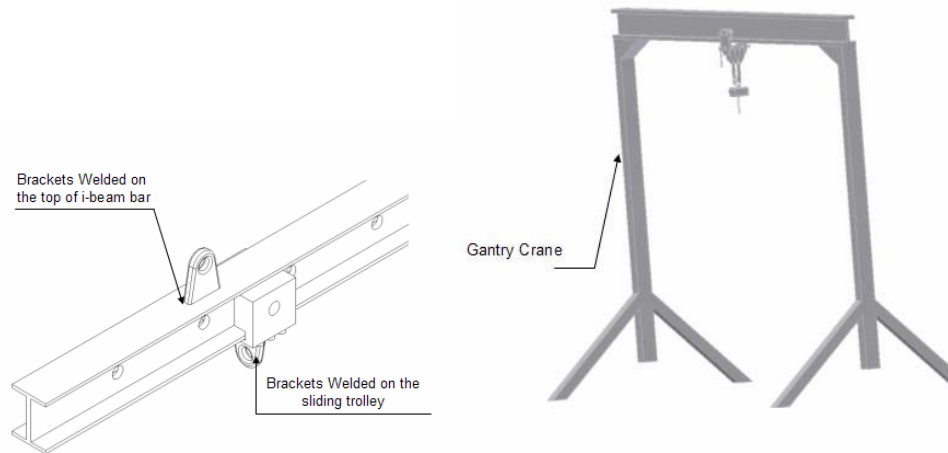


Figure 2. OSB placement mechanism

#### 4-3- Spline production line

In this project, a mechanism was designed and prototyped that is able to produce (size, cut, and make holes) splines with variety of sizes (e.g., 2x4, 2x6, and 2x8 in<sup>2</sup> cross section and 24 ft length) in less than 1 minute. The improvement in productivity compared to that of previous mechanisms was above 100%. This mechanism includes a heavy duty chop saw, two heavy duty drill machines, and sets of tables equipped with rollers.

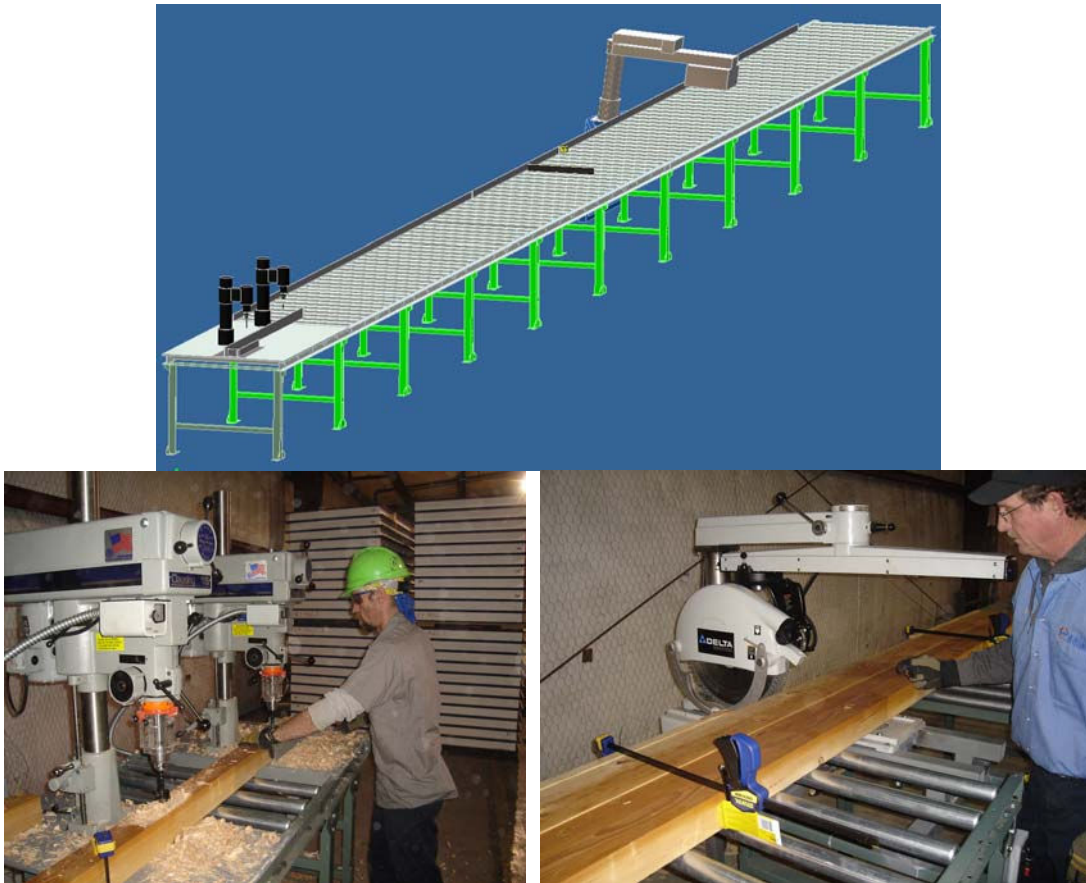


Figure 3. Spline production line

#### 4-4- Roof panel lift mechanism

Installing a roof panel is a costly and time-consuming process that usually takes up to three days (8 hours per day) and cranes are usually rented for about \$150 per hour. Each roof panel is up to 24' long, 48," wide and 8.25" thick. The weight ranges from 200 to 600 lbs each. In this project, a full-scale mechanism was designed to meet the process requirements and restrictions. However, due to time limitations, a small-scale (1/15) model was prototyped.

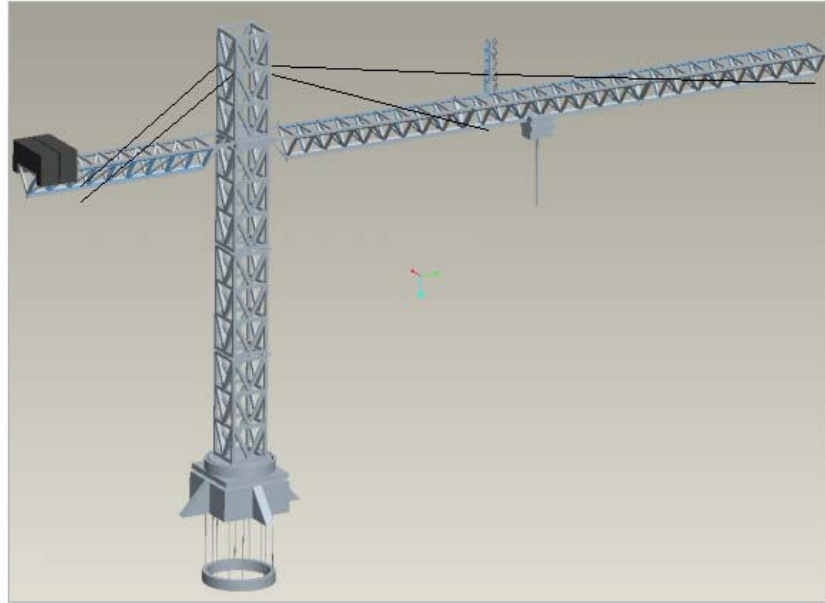


Figure 4. Roof panel lift mechanism

## 5- Conclusions

In this paper, a capstone senior design course for the manufacturing engineering undergraduate program is introduced. Course motivations, objectives, activities and milestones, assessment methods and results, and sample projects are explained. The conclusion from these projects is that the outcome of this course has been satisfactory in all aspects to all stakeholders: students, instructor, project sponsor, panel of experts, and ABET internal evaluator. This success is due to many interconnected factors including, appropriate project (e.g., real world, challenging, and proportionate), sponsor financial and technical support, students' efforts (e.g., team work, preparation, spending enough time, and diligence), faculty performance (e.g., availability, related content coverage, quick feedback, providing tools and materials, and applying proper assessment methods), departmental support (e.g., access to workshops, safety class), and the feedback from the panel of experts.

### A- Appendix: Survey statistics

Students' responses to the pre- and post-semester surveys were matched and analyzed. The return rate for the pre- and post-surveys was 100%. Paired t-test method was used to compare the pre- and post-semester ratings. In this method, confidence intervals for pre- and post-semester results were calculated by the following equations:

$$\bar{x} = \frac{\sum_{j=1}^n x_{(2-1)j}}{n}, \quad s_{(2-1)} = \sqrt{\frac{\sum_{j=1}^n [x_{(2-1)j} - \bar{x}_{(2-1)}]^2}{n-1}}$$

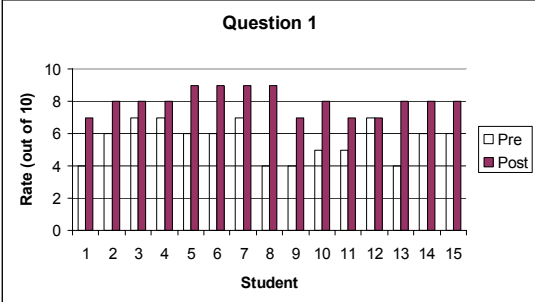
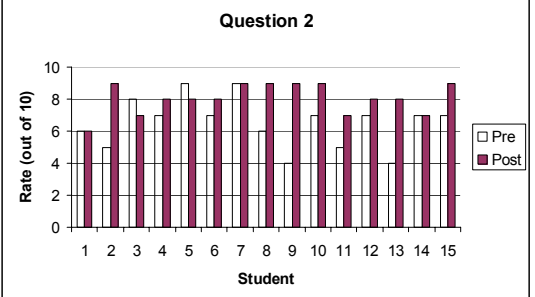
$$hw = \frac{t_{n-1, \alpha/2} S}{\sqrt{n}}, \quad \bar{x}_{(2-1)} - hw \leq \mu_{(2-1)} \leq \bar{x}_{(2-1)} + hw$$

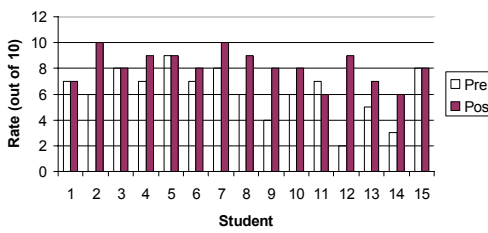
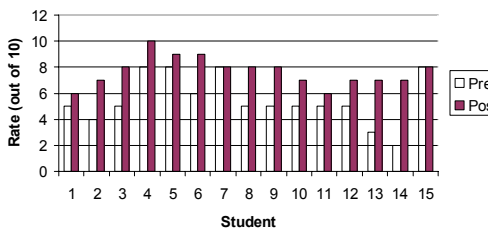
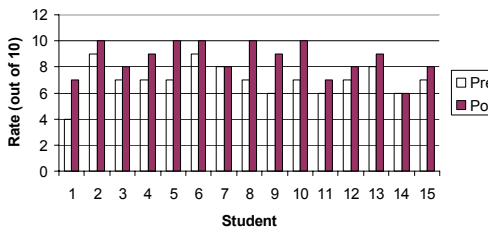
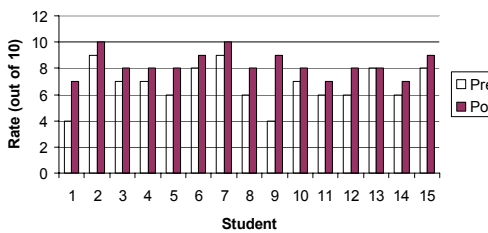
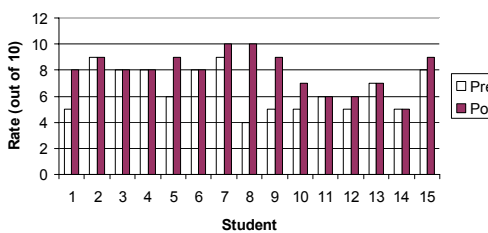
where,

$x_{(2-1)j}$  : Post and pre semester rate difference for student  $j$ ,

$s$  : st. deviation ,  $\bar{x}$  : average,  $\alpha = 5\%$ , and  $n$  : number of samples

Analysis results show that students made statistically significant progress during the semester in all 12 areas in which they were questioned:

Question	Graph	Pre and Post semester difference statistics
<p><b>Quantitative questions (rate 0-10):</b></p> <p>1. How would you describe your knowledge of the link between product and process development?</p>	<p style="text-align: center;"><b>Question 1</b></p> 	<p>Average: 2.4</p> <p>Std. dev.: 1.24</p> <p>Confidence interval: [1.71 , 3.09]</p>
<p>2. How would you describe your ability to solve design problems (operating with incomplete data or with many unknowns)?</p>	<p style="text-align: center;"><b>Question 2</b></p> 	<p>Average: 1.53</p> <p>Std. dev.: 1.85</p> <p>Confidence interval: [0.51 , 2.56]</p>

<p>3. How would you describe your ability to deal with problems for optimum part manufacturing &amp; product assembling?</p>	<p style="text-align: center;"><b>Question 3</b></p> 	<p>Average: 1.93</p> <p>Std. dev.: 2.09</p> <p>Confidence interval: [0.78 , 3.09]</p>
<p>4. How would you describe your ability to estimate product/production cost (knowing how to estimate costs)?</p>	<p style="text-align: center;"><b>Question 4</b></p> 	<p>Average: 2.2</p> <p>Std. dev.: 1.42</p> <p>Confidence interval: [1.41 , 2.99]</p>
<p>5. How would you describe your technical writing skills (e.g. communicating in writing to teachers or other professionals)?</p>	<p style="text-align: center;"><b>Question 5</b></p> 	<p>Average: 1.6</p> <p>Std. dev.: 1.12</p> <p>Confidence interval: [0.98 , 2.22]</p>
<p>6. How would you describe your presentation skills?</p>	<p style="text-align: center;"><b>Question 6</b></p> 	<p>Average: 1.53</p> <p>Std. dev.: 1.19</p> <p>Confidence interval: [0.88 , 2.19]</p>
<p>7. How would you describe your project management skills?</p>	<p style="text-align: center;"><b>Question 7</b></p> 	<p>Average: 1.40</p> <p>Std. dev.: 1.84</p> <p>Confidence interval: [0.38 , 2.42]</p>

<p>8. How would you rate your skills in performing assignments or tasks while being a part of a team?</p>	<p style="text-align: center;"><b>Question 8</b></p>	<p>Average: 1.07 Std. dev.: 1.71 Confidence interval: [0.12 , 2.01]</p>
<p><b>Grades for descriptive questions:</b></p> <p>9. In your opinion, what role does cost have in product development?</p>	<p style="text-align: center;"><b>Question 9</b></p>	<p>Average: 11.33 Std. dev.: 11.25 Confidence interval: [5.1, 17.57]</p>
<p>10. In your opinion, what roles do business plans have in product development?</p>	<p style="text-align: center;"><b>Question 10</b></p>	<p>Average: 32 Std. dev.: 23.96 Confidence interval: [18.73 , 45.27]</p>
<p>11. In practical terms, describe the integration of product and process design?</p>	<p style="text-align: center;"><b>Question 11</b></p>	<p>Average: 28.67 Std. dev.: 31.14 Confidence interval: [11.42 , 45.91]</p>
<p>12. Engineers often face product development constraints. Using knowledge gained in other classes, identify three product development constraints and then make recommendations for how to best deal with each constraint.</p>	<p style="text-align: center;"><b>Question 12</b></p>	<p>Average: 57.67 Std. dev.: 52.81 Confidence interval: [28.42 , 86.91]</p>

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