

## Integrating Rapid Prototyping into Product and Process Development

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**Abstract:** Rapid prototyping concepts and skills are being taught to undergraduate manufacturing engineering students at Texas State University-San Marcos, not as an independent course, but as a part of the broad concept of product and process development. In such approach, students get a hands-on experience in a variety of rapid prototyping processes such as FDM, LOM, Zcorp 3DP, and 3D system's InVision and they apply them in their industry-sponsored or research-based senior capstone design projects. In such approach students get a good understanding about the specifications, cost, and quality of the parts fabricated by each rapid prototyping machine. They also learn how to select the optimum process for each component of their product. In this paper, teaching and assessment methods for such learning experience are explained and a few samples of the previous projects are presented.

### 1- Introduction

The NSF National Science Board in a recent report identified that one of the key challenges in engineering education is in response to global change that has encouraged US companies to outsource their production and service units to overseas. The Board recommended that the education and skills of U.S. engineers should change in a way that cannot be easily replaced by engineers in other countries. Some of the important characteristics of the US engineers should be the ability to solve “complex interrelationships” and “encompass human and environmental factors”[1]. According to a report of the national innovation initiative summit, Innovate America, “innovation will be the single most important factor in determining America's success through the 21<sup>st</sup> century.” [2] These two studies support previous studies conducted by the Society of Manufacturing Engineers (SME) entitled “Manufacturing Engineering for the 21<sup>st</sup> Century” [3] and the criteria set by Accreditation Board for Engineering and Technology (ABET). The SME study identified communication skills, teamwork, project management, business skills, and life-long learning as some key competency gaps in recent graduates of engineering programs. 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.”

Texas State University-San Marcos (Texas State) is a student-centered institution and is training about 28,000 graduate and undergraduate students. High-quality teaching, one-on-one academic and career advising, and the student-friendly system are among the distinctive features

of this university. In the fall of 2000, Texas State introduced a new undergraduate degree in Manufacturing Engineering. Lab-based teaching and hands-on experience have become the hallmarks of this program. Despite a major slowdown in the US economy and especially in the manufacturing sector, the Manufacturing Engineering program at Texas State University has grown. Currently 115 students are studying in this program. Many of our recent graduates have been employed by both local industries and national and international companies such as Toyota, Chrysler, Boeing, Applied Materials, National Instruments, and Dell. In response to growing demand for home-grown engineers in Texas and in the US, in the fall of 2007, the Ingram School of Engineering, including Manufacturing Engineering and two newer programs of Industrial Engineering and Electrical Engineering were formed. It is expected that these programs will grow, both by enrolling new undergraduate students and by adding graduate programs in engineering.

## **2- Rapid prototyping in manufacturing engineering program**

To respond to the key challenges raised by SME, ABET, NSF, and the Innovative America summit, the manufacturing engineering curriculum at Texas State has been modified. While most of limitations and requirements are addressed throughout the four-year curriculum, the capstone senior design course provides the best framework for simultaneously closing all of the gaps and meeting all of the criteria. 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- or research-supported project. In addition, the hands-on and project based teaching approach has been expanded to other courses such as tool design and manufacturing systems design.

Manufacturing Engineering students now have access to a variety of rapid prototyping and rapid tooling machines, including Fused Deposition Machine (FDM), Laminated Object Manufacturing (LOM), ZCorp 3D printer model Z450, InVision LD 3D modeler by 3DSystem, and PlasmaCAM CNC cutter. In addition, multiple research activities in the area of freeform fabrication are in progress. One of these research studies is on the Selective Inhibition of Sintering (SIS) rapid prototyping process and another one is on automated construction.

No specific course entitled “Rapid Prototyping” or similar names is yet available in the Manufacturing Engineering program at Texas State. Additionally, due to the State of Texas mandate, the number of credit hours in this program should be reduced from 137 hours to 120 hours. However, despite these facts, there are many opportunities available to students to participate in freeform fabrication activities. Interested students can join developmental studies for new freeform approaches and all students in manufacturing engineering program acquire enough knowledge and effective hands-on experience in working with variety of rapid prototyping systems. In this approach, rapid prototyping is taught as part of the wider concept of product and process development.

## **3- Student involvement in research**

Undergraduate students in manufacturing engineering have been involved in the SIS rapid prototyping process and automated construction development as volunteers, paid researchers, or as part of their capstone senior design or tool design course projects. For the recent case (course

projects), defining goals and objectives for these types of research which needs to be finished within 14 weeks and is essential. Among the projects that the students completed were a finger-based mask system for the heating system of the SIS process, a fixed heating system for the SIS process, an adjustable array-based heating system for the SIS process, and an adjustable die system for the automated curb making process. The ultimate achievement of these types of project is that undergraduate students were introduced to the process of presenting their work at conferences and submitting it to journals. This involvement gives students a sense of self-esteem and peer recognition [5-12]. These students have used variety of CAD software and manufacturing processes in addition to rapid prototyping machines.

#### **4- Integrating rapid prototyping learning into product and process development concept**

In this approach, rapid prototyping is taught as part of the product and process development. The students become familiar with freeform fabrication concept and rapid prototyping equipments in a hands-on approach. They can then apply their knowledge of rapid prototyping and other fields to their capstone projects.

Students start their capstone design project with a need description for a specific application. Then they follow a procedure to finalize their work. Major steps of such a procedure include team building and project management, identifying customer needs, innovation and creativity, defining product specifications and quality function deployment (QFD), concept generation, concept selection, design, design for manufacturing and assembly, robust design and design of experiments (DOE), rapid prototyping and rapid tooling, manufacturing, assembly, test, failure mode and effects analysis (FMEA), and business plan. During the semester, students review a variety of manufacturing processes and become familiar with new processes such as rapid prototyping machines. They also conduct small hands-on work by these machines as a weekly assignment. Toward the end of the semester, rapid prototyping machines are used in capstone design and tool design projects to make visualization and conceptual parts, a pattern or mold maker for the cast and foundry process, and to build functional part in a product or process.

#### **5- Course assessment**

In the capstone design 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. Each project is reviewed and evaluated by the sponsor before it is presented to the public. Members in the panel of experts (including industry participants and selected faculty) express their views and offer feedback on individual projects and on the entire class by completing two forms. The first form is the competition form on which each panel member ranks each team based on the quality of the project and comments on its strengths and weaknesses. In addition, each panel member fills out an ABET form that evaluates the performance of the entire class. The best project, as selected by the panel of expert vote, receives certification. Also, students participate in a pre- and post-semester survey. This survey consists of two parts: quantitative questions (that students rank their knowledge about different subjects) and subjective questions (that students answer a set of technical questions). Students' responses to the pre- and post-semester surveys are then matched and analyzed (appendix A).

## 6- Sample rapid prototyping applications in senior capstone design projects

During the last five years between 4 to 6 capstone design projects have been presented annually. Most of the projects use at least one rapid prototyping technology. This section describes a few of these projects.

### 6-1-Keychain design and prototype

In this project an LOM machine was used to prototype a pattern to make a mold for the casting process.

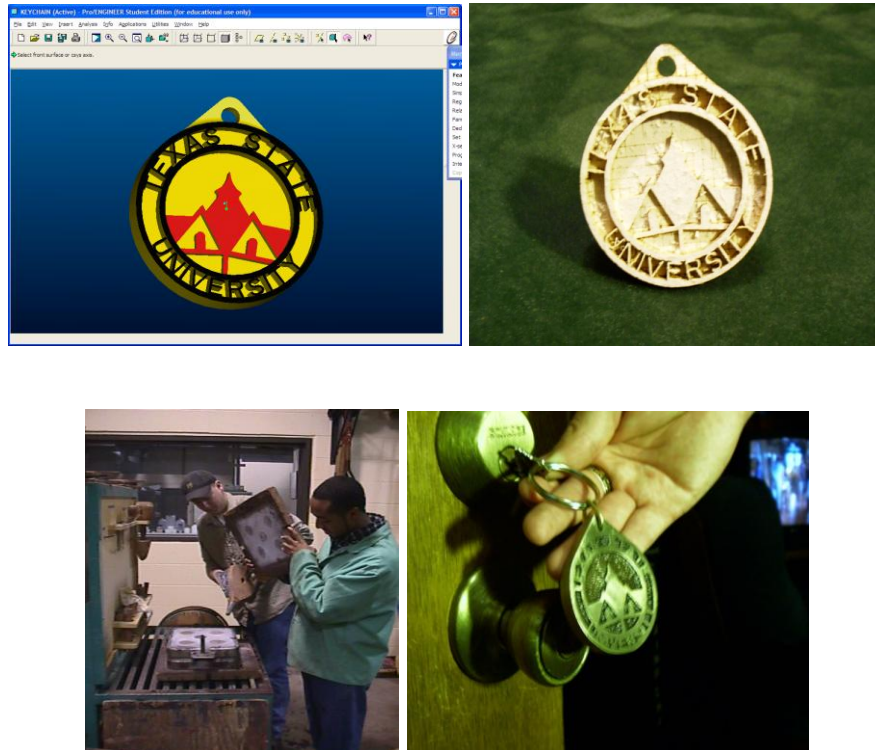


Figure 1. Keychain designing, prototyping, and casting

### 6-2-Light holder for the hand-held drills

In this project, FDM machine was used to build a functional part (light holder).

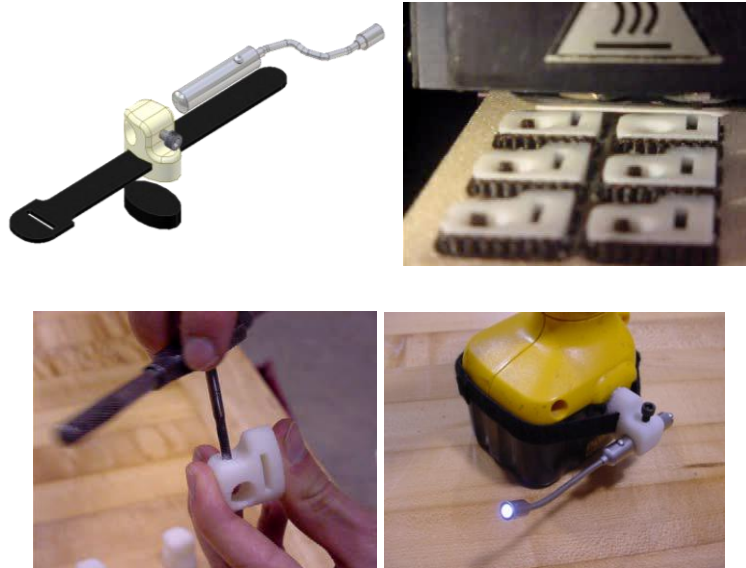


Figure 2. Light holder design and prototyping

### 6-3-Luminaire fixture design and development

In this project, an FDM machine was used to build the main body of the proposed design for the new luminaire fixture.

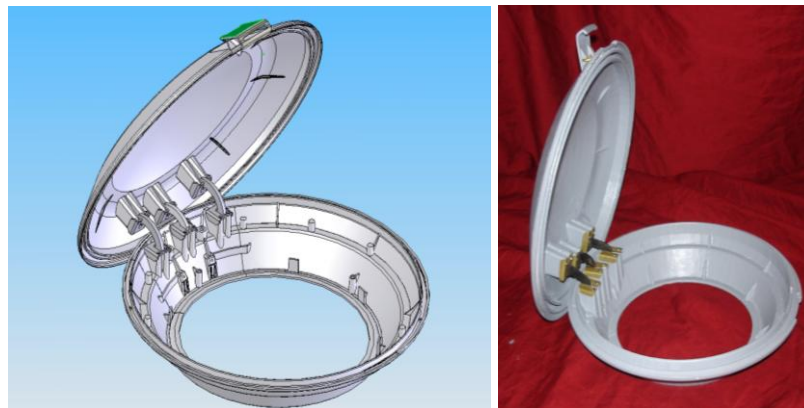


Figure 3. Luminaire design and prototyping

### 6-4-Battery terminal cap

In this project, an InVision 3D printer was used to build a cover cap that was designed for covering the battery terminal connections. These batteries have many applications, including electrical forklift, load leveling (e.g., USP, Wind farm), and special applications such as South Pole telescope.



Figure 4. Battery terminal cap prototyping

#### 6-5-Oriented strand board (OSB) tilt and transfer cart

In this project, students 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 lbs. This cart system is designed for a hydraulic tilt mechanism; however, the rotation mechanism was successfully tested by use of a forklift. PlasmaCAM machine was extensively used for building parts for this project.



Figure 5. Tilt and transfer cart designing, manufacturing, and testing



## 6-6- Miscellaneous

In many occasions parts need to be fabricated for a research and/or collaborative work with another department or an industry partners. In such cases, students are asked to get involved in building those parts to get more experience with these rapid prototyping processes. Figure 6 illustrates a few samples built by the Zcorp 450 machine for a collaborative work with Anthropology department and a local industry.



Figure 6. A light fixture prototype (left) and a rapid prototyped skull by the Zcorp 450 machine.

## 7- Rapid prototyping: a tool for outreach

In addition to educational and research activities, available rapid prototyping machines have been utilized to attract more high school students to the engineering field. In different occasions such as engineering weeks and open house days students visit the department laboratories. Rapid prototyping has always been very impressive and “cool” technology for them. Also, occasionally some collaborative projects with other departments are offered to high school students that are participating in the university’s summer camps. For example, this summer a rapid prototyping project (giving thickness to the laser scanned object files) is offered to a team of talented high school students participating at Texas State University’s Siemens honor summer mathematics camp.

## 8- NSF Research Experience for Undergrads (REU) program

Under an NSF REU center grant entitled as “Micro/Nano Assembly Workcell Via Micro Visual Sensing and Haptic Feedback”, Texas State is hosting 10 undergraduate students for 10 weeks in Summer 2008 and 2009. In this research four teams of students in the areas of Microelectromechanical systems (MEMS), 3D Vision, Robotics, and Micro grippers are involved in design, development, and test of their subsystems to integrate them as one automated system. Available rapid prototyping capabilities have been very helpful in their design stage before finalizing their micro scale system. Figure 7 illustrates some of the rapid prototyping applications in this research.



Figure 7. Rapid prototyping application in micro gear and gripper design and 3D Vision.

## 9- Conclusions

Rapid prototyping concepts and skills are being taught to undergraduate manufacturing engineering students at Texas State University, not as an independent course, but as a part of the broad concept of product and process development. In such approach, students get a hands-on experience in a variety of rapid prototyping processes and they apply them in their industry-sponsored and research-based senior capstone design projects. In such approach, students learn how to select and use a rapid prototyping machine and how to evaluate and test their final product.

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## Appendix A: 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:

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

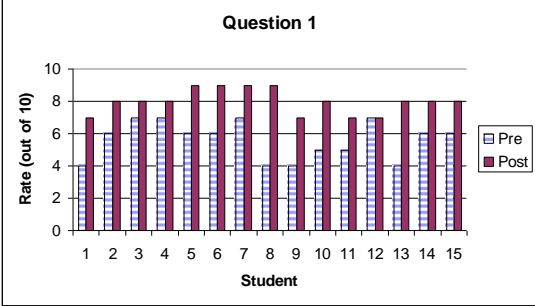
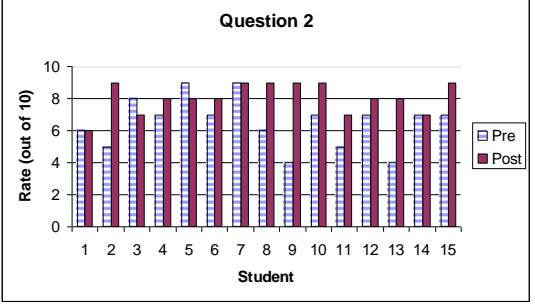
$$hw = \frac{t_{n-1, \alpha/2} s}{\sqrt{n}}, \quad \bar{x}_{(2-1)} - hw \leq \mu_{(2-1)} \leq \bar{x}_{(2-1)} + hw$$

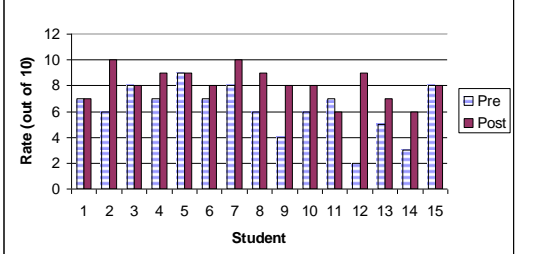
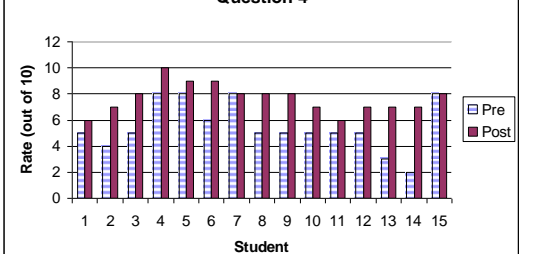
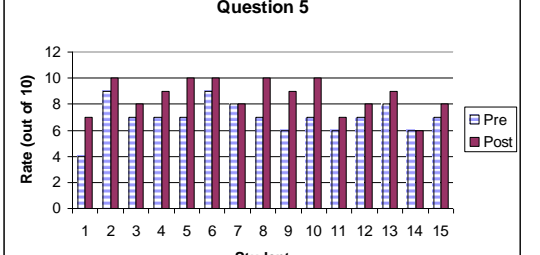
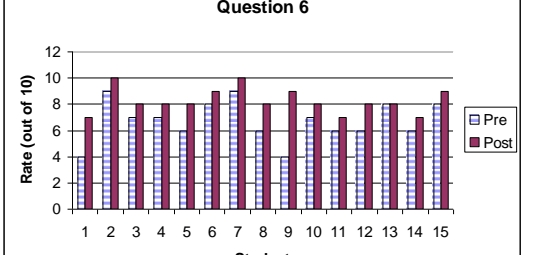
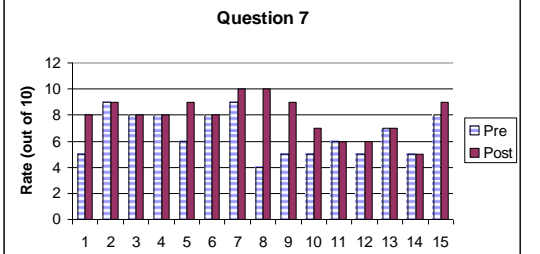
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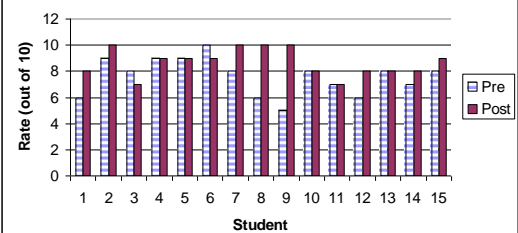
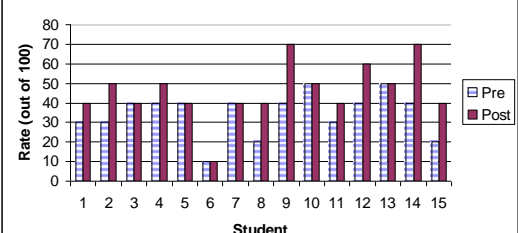
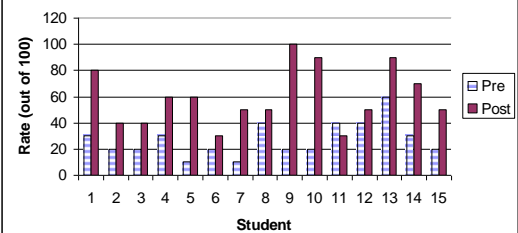
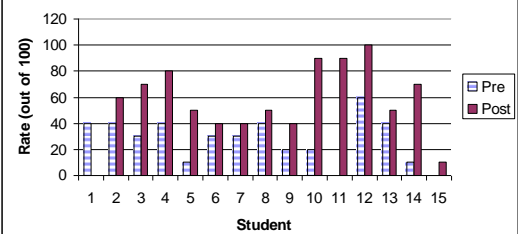
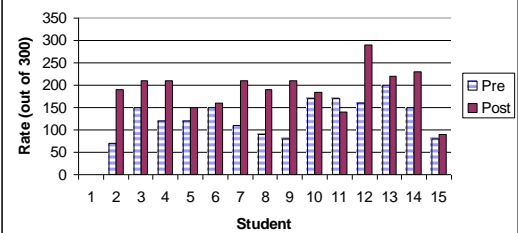
$x_{(2-1)j}$  : Post and pre semester rate difference for student j,

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>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>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</p> <p>Std. dev.: 1.71</p> <p>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</p> <p>Std. dev.: 11.25</p> <p>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</p> <p>Std. dev.: 23.96</p> <p>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</p> <p>Std. dev.: 31.14</p> <p>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</p> <p>Std. dev.: 52.81</p> <p>Confidence interval: [28.42 , 86.91]</p>