Effective Capstone Project in Manufacturing Design Engineering Program

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Effective Capstone Projects in Manufacturing Design Engineering Program

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Abstract

Final program projects (capstone course) in manufacturing design engineering at National University are intensive experiences in critical analysis, designed to broaden students’ perspectives and provide an opportunity for integration of coursework in the area of manufacturing design engineering. This paper summarizes capstone project experience in an undergraduate manufacturing design engineering program. The two projects include an office chair design and development of an improved balloon marker placement system for catheter manufacturing. This paper summarizes the design methodologies and strategies adopted by the students. In addition, this paper summarizes how a capstone project in manufacturing design engineering should be designed for maximum effectiveness based on the experiences from this project. This paper also highlights do’s and don’ts list.
Introduction

A capstone course can provide an invigorating experience to students in their program of study since it integrates concepts and skills learned throughout the academic tenure. Final program projects are intensive experiences in critical analysis, designed to broaden students’ perspectives and provide an opportunity for integration of coursework in the area of specialization. Typically, projects focus on the application of materials learned throughout the program to solve multi-faceted problems such as those they would encounter in the students’ post-academic future employment. In these projects, students select project topics under the guidance of a faculty advisor, analyze the problem and formulate a detailed plan to reach a solution, perform necessary evaluations and/or experimentations, identify and/or propose meaningful results and solutions, test the proposal to the extent possible, and prepare a detailed report and associated presentation. Projects are done usually in teams, however, a few individuals are allowed to work alone based on personal constraints. The ‘front end’ project plan and the ‘back end’ documentation and presentation are both important elements. Since the entrance into the capstone projects follows completion of other courses, faculty project advisors can assign problems that are not only relevant to the students’ interests but also are helpful in reinforcing the concepts taught.

Typical learning outcomes for such a culminating project experience include students demonstrating capability to:

- Define a specific problem or study and evaluate critically a given project’s feasibility.
- Present a comprehensive review of relevant literature.
- Identify sources of relevant data, generate and/or gather data as appropriate, and provide in-depth analyses.
- Identify, describe and apply appropriate models for drawing conclusions.
- Create a comprehensive project report based on the findings that relate to all essential elements of the project.
- Defend the project’s findings during oral presentation to faculty, class and, if applicable, external project sponsors/clients.
National University’s courses are offered in an intensive one-course-at-a-time, one course per month format. This includes 45 instructor-student contact hours per month, and capstone projects require two courses done over a three month period. Since these constraints require projects to be completed within a time intensive setting, preparation and execution have to be flawless to meet the learning outcomes previously established. There is little room for error or slack. This paper presents a process to complete an effective capstone project. In addition, this project provides a do’s and don’ts list.

Capstone Project

The Integrated Project Course is the capstone course of National University’s curriculum. It is the last two classes taken by the students before graduation. The two classes run for three instructional months. The initial class (1 month) focuses on establishing an approved project proposal. Although the capstone course is done at the end, students are encouraged to identify and select a project about six months before graduation. Typically, projects are proposed by corporate sponsors, frequently employers of the students or corporations looking for answers to a problem through the lead faculty (faculty in charge of program). As a result, students deal with real problems of significant issue to the sponsor and typically involve engineering, technology, science, and business related issues. Interdisciplinary teams of two to three students are assigned to each project. These teams work with faculty members and representatives of the sponsors to develop detailed, implementable solutions. At the end of the course, students present the project presentations to the sponsoring company. Student teams typically travel to the sponsor’s location to learn about the problem and meet the company representatives with whom they will work.

Capstone Process

Since the Capstone project duration is short, National University has a detailed Capstone process. The infrastructure and associated assistance are built in for students and faculty members to get assistance as and when required. The project class is led by instructors. They are typically in charge of the capstone process including student progress. Project advising is done by project advisors who are also faculty members. However, in some instances, the capstone instructors and project advisors could be one at the same. Corporate sponsors, when involved,
ensure that the sponsored projects are consistent with corporate needs. Below are the list of steps developed for students, instructors, and project advisors to follow.

All students are expected to:

1. Consult with a faculty member of their choice (project advisors; subject matter experts), select a project, and find a sponsor from an external organization (Typically, the sponsor could be from either a student’s workplace or from an organization with which he/she may have some contact).
2. Develop a proposal that defines the focus and scope of the project in consultation with the project advisor, sponsor, and instructor for the capstone class.
3. Obtain a detailed letter of support from the external organization project sponsor.
4. Develop the project individually or collaboratively with other students from the class.
5. Submit for approval, one month prior to defense, a customized, deliverable rubric for project assessment created in consultation with a Capstone Project Advisor.
6. Deliver a project report on or before the final presentation

The instructors will:

1. Ensure that the project selected is relevant to the student’s area of specialization, has academic relevance, and will produce learning outcomes relevant to the program.
2. Review that the project selected is feasible within the timeframe allotted.
3. Help refine the project goals and outcomes as needed.
4. Identify and provide any help required to have a good start on the project.
5. Consult with the project sponsor with regard to all issues including project goals, access to data, confidentiality, and project details.
6. Provide a clear assessment system with minimal ambiguity.
7. Monitor the students’ progress on a weekly basis to ensure a successful capstone experience.

The project advisors will:
1. Let the students know whether the project selected is in their field of expertise and whether they are interested in supervising the work.

2. Review that the project selected is feasible within the timeframe allotted.

3. Help refine the project goals and outcomes by working with students, project sponsors, and instructors.

4. Identify and provide any help required to have a good start on the project.

5. Consult with the project sponsor with regard to all issues including project goals, access to data, confidentiality, and project details.

6. Monitor the students’ progress on a weekly basis to ensure a successful Capstone experience.

7. Ensure that the project is the student’s original work.

8. Ensure that the project meets the requirements specified in the description and guidelines.

In an undergraduate degree program, the projects may be defined by the course instructor and/or lead faculty. In these instances, the students have only to select the instructor specified projects.

**Selecting a Capstone Project:**

Students are encouraged to select a client organization that fits their goals for the program. Since most of the students in National University are working adults, the students often pick their current employer for doing their Capstone project. If a student is interested in entering into a new area of specialty, he/she is encouraged to select an organization of his/her choice (this organization could either be a prospective employer or one that is representative of an industry that he/she would like to explore). Typically, the instructor or lead faculty will help the students to connect with an organization of their choice and interest. Since the goal of the Capstone project is to demonstrate a student’s mastery over all aspects of the area of his/her specialty including problem identification, technology selection and integration, risk analysis, project management, and implementation, the student is advised to pick a discipline emphasis that caters to his/her interests.
Finding a Sponsor

Although some potential sponsors contact National University lead faculty with prospective projects, students are encouraged to seek their own sponsors as well. The recommended process for obtaining sponsorship follows the following sequence:

- Identify a potential sponsor with the help of faculty, colleagues, fellow students, employers, or other means.
- Ensure that the student and sponsor clearly understand the Capstone project’s process, timelines, and guidelines.
- Develop a written list of questions about the organization and available potential projects.
- Provide potential sponsor information regarding the students’ qualifications.
- Meet face to face with the potential sponsor and discuss project details.
- Communicate clearly with the potential sponsor about the goals for a Capstone Project, and seek to match students’ proposed solution with a problem faced by the prospective sponsoring organization.
- Evaluate the feasibility of completing the project through discussions with the potential sponsor, instructors, colleagues, fellow students, and lead faculty.
- Contact the potential sponsor on or before the agreed-upon date to convey students’ decisions.

It is important to make sure that the sponsor selected (or a designee) will be the principal contact for the entire duration of the project. Typically, a letter of support from the organization that lays out the terms of the project along with mutual expectations is obtained.

Project Logistics

The capstone course is three month in duration. As a start, a course outline with instructional plan is provided to the students as a way to familiarize the course process. Each
week, a set of assignments to be done/covered (or due) is defined (Table 1). This list of milestones is a starting point for developing a specific project plan. During the course time, students will meet with the instructor in charge of this course twice a week during the first month and once a week during the second and third month. The students are asked to prepare a formal proposal that defines the project, lays out the requirements, and expectations that is presented and signed off at the end of month 1 regarding their projects, their team members, project sponsor and timeline of activities. Drawing on the information obtained from this proposal, students and their instructors may refine the scope, goals and outcomes of the selected project. Since the entire project has to be completed in two or three months, including all documentation, all details pertinent to the project including expected assignments on a weekly basis would be laid out. After this introductory meeting, teams will schedule weekly status meetings with the instructor. These are formal meetings in which each team member will present a report on his/her particular activities and the status of his/her individual deliverables during the preceding week. Attendance at these meetings is mandatory unless specifically excused. Failure to attend the meeting or a show of chronic inactivity as determined from the weekly status report will significantly affect a team member's participation credit. Teams are also expected to meet twice a month with their project sponsor to ensure that they continue to align with the sponsor's vision and have not deviated from the sponsor's expectations. Sponsors are viewed first as a customer and only secondly as a resource. Hence it is the team's responsibility as well as the instructor to make sure that the work is proceeding as per the plan. Each month, teams are asked to present their project progress to the rest of the class. A project post-mortem is held to ensure that the proposed results are indeed the best solutions to the problem proposed. A final public presentation is made to the review committee (faculty members, lead faculty) and sponsors at the end of the project.

<table>
<thead>
<tr>
<th>Week</th>
<th>Assigned readings</th>
<th>Assignments</th>
<th>Due dates and times</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Course outline, Capstone project requirements</td>
<td>Form team, define a problem, Select a sponsor</td>
<td>Week 1 Sunday, midnight (PST)</td>
</tr>
<tr>
<td>2</td>
<td>Hypothesis, problem definition, Needs analysis</td>
<td>Complete Chapter 1</td>
<td>Week 2 Sunday, midnight (PST)</td>
</tr>
<tr>
<td>3</td>
<td>Library Search</td>
<td>Identify key relevant papers and internal sponsor</td>
<td>Week 3 Sunday, midnight (PST)</td>
</tr>
<tr>
<td>Chapter</td>
<td>Research</td>
<td>Task Description</td>
<td>Deadline</td>
</tr>
<tr>
<td>---------</td>
<td>----------</td>
<td>------------------</td>
<td>-------------------</td>
</tr>
<tr>
<td>4</td>
<td>Research Papers</td>
<td>Complete Chapter 2</td>
<td>Week 4 Sunday, midnight (PST)</td>
</tr>
<tr>
<td>5</td>
<td>Research Papers</td>
<td>Develop Methodology and Complete Chapter 3</td>
<td>Week 5 Sunday, midnight (PST)</td>
</tr>
<tr>
<td>6</td>
<td>Research Papers</td>
<td>Collect data and analyze data</td>
<td>Week 6 Sunday, midnight (PST)</td>
</tr>
<tr>
<td>7</td>
<td>Research Papers</td>
<td>Collect data and analyze data, Complete an in-depth analysis of all applicable variables</td>
<td>Week 7 Sunday, midnight (PST)</td>
</tr>
<tr>
<td>8</td>
<td>Research Papers</td>
<td>Complete Chapter 4</td>
<td>Week 8 Sunday, midnight (PST)</td>
</tr>
<tr>
<td>9</td>
<td>Research Papers</td>
<td>Complete Chapter 5, Abstract, Table of Contents</td>
<td>Week 9 Sunday, midnight (PST)</td>
</tr>
<tr>
<td>10</td>
<td>Steps for Thesis Guidelines</td>
<td>Complete the entire thesis</td>
<td>Week 10 Sunday, midnight (PST)</td>
</tr>
<tr>
<td>11</td>
<td>Visual Aids Preparation Guidelines for Oral Presentation</td>
<td>Complete PPTs for Presentation and Practice Presentation</td>
<td>Week 11 Sunday, midnight (PST)</td>
</tr>
<tr>
<td>12</td>
<td>Guidelines for Oral Presentation</td>
<td>Final Presentation</td>
<td>Week 12 Saturday or thereabout</td>
</tr>
</tbody>
</table>

Chapter 1: Introduction - The statement of the problem, background of why this problem needs to be studied.

Chapter 2: Literature Review – This section should contain all work related to the proposed topic including chronological research progress made to date.

Chapter 3: Methodology – Answers the question “How do you plan to study this problem?”

Chapter 4: Findings – Answers the question “What were the actual results of the study?”

Chapter 5: Conclusions and Recommendations – Answers the question “So what?”

References: Published peer reviewed documents and internal reports.

**Table 1: Instructional Plan for the Course**

Class Structure

A major goal of the Capstone project is to familiarize students with a corporate team environment, where responsibility for getting things done belongs to the team and its members.

A typical class will have 12 – 15 students, and these students will be grouped into five project teams. This size will provide students with opportunities to get personal attention from the faculty supervising their project. Initially, the Capstone class will have a structure similar to that of other classes. Each meeting will consist of a lecture and class interaction. The goal of these lectures is to help reinforce students' knowledge of the program specialization and project management practices. However, by the third week of the Capstone course, each team will meet the instructor alone to review the progress made, and get answers to relevant questions. This 30-
45 minute status meeting each week will give students a chance to allow their instructor to gain some visibility into team performance, dynamics, and effort invested by individual team members. In addition, the status meetings will ensure that each team makes steady, consistent progress towards completing the project.

Projects

In 2012-2014, two sets of capstone project classes were held. During this time, two different methodologies were adopted in selecting projects. In one of the classes, projects were selected by the students in consultation with their employer. In the second class, one project was selected for all students. The different approach adopted was to analyze what works better and how to streamline the capstone process.

Employer Sponsored Projects:
Development of an Improved Balloon Marker Placement System for Catheter Manufacturing

Abbott Vascular, Inc. manufactures cardiac catheters for use by physicians to open blood vessels that are partially obstructed in coronary artery disease. A group of 4 students who work in the manufacturing department at Abbott chose to use the Capstone project to address a newly identified issue impacting manufacturing efficiency.

![Cardiac Catheter Diagram]

Figure 1. Cardiac Catheter

Analysis of manufacturing line yields and product scrap led to the identification of a specific defect being responsible for the majority of the scrap. The issue related to the consistent placement of 2 radio-opaque bands at either end of the balloon, which enable the physician to correctly position the balloon within a blood vessel under fluoroscopy. Manufacturing of
catheters is a surprisingly hands-on process including the operator-mediated physical placement of the radio-opaque bands using visual guides. The entire process requires (1) manual setup of workspace and alignment tool for a specific catheter size, and for each catheter (2) physical placement of band within a 0.1 mm tolerance, (3) pre-crimping of band with tweezers, (4) insertion into swaging machine for final crimping, followed by (5) visual confirmation of band spacing against a laminated template. This process is performed ~2,400 times per work shift by a single operator. The process depends on the accurate visual alignment by the operator throughout the work shift (8 hr.). The three critical steps were (1) positioning the marker bands, (2) pre-crimping the bands, and (3) verifying the band positions. The goal was to eliminate relatively subjective decisions on the part of the operators, which would improve product yields as well as improve the ergonomics of the workstation.

Instructor Sponsored Project:
DesignTech, the largest design and manufacturing firm in the U.S. has been hired to design an ergonomic office chair by IKEA, the largest furniture retailer in the world. The students, as a DesignTech team are requested to come up with an office chair design ready for manufacturing. The chair has to be used by individuals with weight 250 lbs, and height 6’ 6” in 8 hour per day in an office environment. It is expected that the person using the chair is working on the computer and hence expect to have the required ergonomic chair design features built in. The students are asked to provide design details ready for manufacturing including features (ergonomic and eco features), specification, state of art cushions, material section, cost and manufacturing process and strategies.

The office chair is the most frequently used piece of office equipment. Experts have identified several features characteristic of well-designed ergonomic office chairs. With increasing numbers of computer users in the workforce, the computer office chair has received great attention. It is presently estimated that 45 million American workers spend some time each day using a computer and keyboard. Approximately 30 million workers use the office chair, computer, keyboard, and pointing devices as their primary work equipment each day, all day, and up to 8 hours per day or more. Computer use has been linked to several types of injuries known as “Upper Extremity Repetitive Stress Injuries” and “Work Related Musculoskeletal
Disorders” (WRMSDs) with the upper extremities (UE) or arms, forearms, wrists, hands, and fingers as well as the neck, back and lower extremities (LE) or legs.

Most office chairs today offer a few necessary ergonomic features that are a must. The students are asked to consider the variables including tension adjustment, chair tilt lock, seat height, arm height, contoured seat cushions, width adjustable arms, synchro tilt movement, waterfall seat edge and retractable settings\textsuperscript{2,3,4}.

Design Process
Employer Sponsored Projects:
The team understood the problem fairly well as they had worked on either the specific product line or similar manufacturing lines in varying capacities. The project involved the design, development, and testing of two tools that would eliminate operator-induced variability. The approach was to eliminate the visual component as much as possible and replace it with mechanical constraints for steps 1-3 (tool 1), and step 5 (tool 2). The project included tool material selection, tool manufacturing process, process implementation requirements, medical device regulatory requirements, costs savings, and manufacturing implementation issues, as well as training needs. Tool #1 included the ability to remove operator dependency in the first 3 steps of the process (Fig. 2) and Tool #2 simplified the verification step and was derived from the first tool (Fig. 3).

This project was of sufficient value to the corporation that the sponsor approved up to 3 hr. during the work shift for half the team. Other team members contributed after their normal shift was complete. Additionally, the sponsor enabled pilot manufacturing tests of the developed tools, which allowed the team to provide actual manufacturing test data during the time frame of the project. As a corporate project and relating to a medical device, the team had to ensure they followed all of Abbott product and process development guidelines as part of this project. As employees of Abbott, the entire team was familiar with these corporate requirements.
The team followed a modified phase-gate process based on milestones including project proposal, requirements documentation, design review, prototyping, test plan development, and test plan results (Fig 2, tool #1; Fig 3, tool #2).

![Design Process - Hand Drawings to CAD to Prototype to Final Tool](image1)

**Figure 2. Design Process - Hand Drawings to CAD to Prototype to Final Tool**

![Verification Tool (Tool #2)](image2)

**Figure 3. Verification Tool (Tool #2)**

This project illustrates the impact of extreme corporate support for student projects. Not only did the students design and implement two related tools, which would have been sufficient to satisfy the capstone requirements, they were able to implement a manufacturing test of the tools accelerating their full-scale implementation for the corporate sponsor. This enabled the students to clearly demonstrate cost-savings projections. Indeed, as this project ended, a new team within Abbott Vascular began validating these new devices for formal manufacturing. With such strong buy-in by the corporate sponsor, a challenge for the instructor was to ensure the team understood
the boundary of the National University requirements and the sponsor’s needs. A second challenge was to ensure that documentation was completed in a timely manner.

Instructor Sponsored Project:
Each team approached the project differently, however, both started with the goal of incorporating both innovation and functionality in order to ensure complete customer satisfaction. Each design incorporated the best industry practices and used accepted industry standards such as, the Business and Institutional Furniture Manufacturer's Association (BIFMA) guidelines considering anthropometric measurements of physiological human characteristics, office chair dimension criteria, general furniture design guidance, as well as ergonomic office chair constraints. Each team defined the key characteristics of an ergonomic chair through research regarding past chair designs and comparative analysis of various ergonomic office chairs to meet the desired needs of the customer. They utilized modular design DFMA (design for manufacturing assembly) principles. Each team segmented the chair into four subassemblies namely base, seat, backrest, and armrests. Typically, the student teams started with napkin sketches that were created during the brainstorming phase of the design and then used Solid Works in designing each and every part. Each team employed a novel approach in creating an office chair that can be customized to the individual user. The teams integrated related course materials in the design (materials selection, strength of materials, stress analysis, optimization, and manufacturing strategies).

Each team focused on customer requirements namely form, function, quality, sustainability and cost. The final output includes complete design, manufacturing drawings, bill of materials, cost and manufacturing strategy. In addition, each team had performed risk analysis and provided appropriate solutions to overcome.

Figure 4 provides a snapshot of an office chair design by one team. Of the five teams started this course, three of them completed within the allocated three months period. The remaining two teams have had team related personal issues and hence could not complete within the three months’ time frame. They are currently working on the project. One of the teams has applied for a provisional patent for their design.
Capstone Project Examination

The examination for the capstone project included an oral presentation and a written document. The instructor in consultation with the lead faculty appointed a committee of faculty/non-faculty members as examiners. The oral examination was used to test a student's level of knowledge and presentation skills. Table 2 provides the rubric for presentation while the Table 3 summarizes the rubric for the written assessment. The oral exam constituted 25%, the written part 65% and participation 10% of the total score. The oral examination lasted 30 minutes, and further time was allotted for questions. Copies of the capstone project were sent to the examiners for review. Through the examination, students had to convince that their capstone project made a contribution to knowledge and the project demonstrated the students’ capacity to carry out design incorporating materials learned.
Table 2: Rubric for Capstone Project

<table>
<thead>
<tr>
<th>Evaluation and Feedback</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Presenter(s)</td>
<td></td>
</tr>
<tr>
<td>Topic</td>
<td></td>
</tr>
</tbody>
</table>

Rate the presentation on the following factors by circling the number that identifies your judgment of the presenter(s) performance.

### Structure and Organization

<table>
<thead>
<tr>
<th>Value/Quality</th>
<th>Poor</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structure</td>
<td>Low</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Organization</td>
<td>High</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

1. Introduces Self + Team (Uses Topic Transition Introductions)
2. Provides an Overview of Topic or Agenda of Key Ideas
3. Identifies Benefits to Audience (Learning Outcomes)

### Development of Main Points

1. Organizes/Structures Ideas to Flow Together
2. Clearly Describes + Emphasizes Key Ideas
3. Illustrates Main Points with Examples, Experience, Stories, etc.
4. Analyzes/Compares + Evaluates Ideas
5. Relates Ideas to Audience’s Experience + Knowledge
6. Uses Supporting Data, Information, Quotes + References
7. Interacts with + Engages Audience through Dialogue + Exercises

### Concluding Summary

1. Restates Objectives of Presentation
2. Summarizes Key Ideas
3. Reinforces/Repeats Benefits to Audience (Learning Outcomes)
4. Responds to Audience Questions + Comments

### Delivery and Style

1. Uses Specific Terminology/Language + Word Pictures/Images
2. Speaks with Appropriate Loudness, Speed, + Voice Inflection
3. Uses Gestures + Body Language
4. Demonstrates Enthusiasm for Subject + Interest in Audience

### Technology

1. Produces Quality Visual Aids + Uses Effectively
2. Provides Quality Materials + Uses Handouts Effectively

### Total Time

**____________________________**

**Final Score**

Add Numbers to 100

**Comments**

**Presentation**

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**TABLE 2: CAPSTONE WRITTEN PROJECT EVALUATION FORM**
<table>
<thead>
<tr>
<th>Area</th>
<th>Outstanding (9-10)</th>
<th>Good (7.5-9)</th>
<th>Fair (6-7.5)</th>
<th>Poor (below 6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Presentation</td>
<td>The student has adhered to all of the standards outlined in the Capstone project requirements by National University. In addition, all protocols regarding the citing of sources (if applicable) have been followed.</td>
<td>The student attempted to provide accurate and relevant information, but had some difficulty furnishing sufficient evidence to fully answer the question or support his/her thesis.</td>
<td>The student has basically ignored many of the standards outlined in the Capstone project requirements by National University. Furthermore, the student has failed to cite appropriate sources.</td>
<td></td>
</tr>
<tr>
<td>Facts</td>
<td>The student provided accurate information relevant to the topic. The detail and scope of the information incorporated into the project demonstrates considerable familiarity with the topic.</td>
<td>The student attempted to provide accurate information relevant to the project. However, information containing greater detail and scope could have been provided.</td>
<td>The student attempted to provide accurate and relevant information, but had some difficulty furnishing sufficient evidence to fully answer the question or support his/her thesis.</td>
<td></td>
</tr>
<tr>
<td>Analysis</td>
<td>The student demonstrated understanding of the question / problem / thesis from different perspectives. Facts, key concepts and principles were presented in an orderly fashion. Inferences were logically sound and conclusions were well supported.</td>
<td>The student demonstrated difficulty grasping the question / problem / thesis. Moreover, some of the facts, key concepts and principles are presented in a disorderly fashion. The student may have made some erroneous inferences and/or reached unsupportable conclusion was found.</td>
<td>The student failed to understand the question / problem / thesis. Presentation of facts, key concepts and principles is disorderly and there are multiple errors in reasoning.</td>
<td></td>
</tr>
</tbody>
</table>

Area: Outstanding (9-10) Excellent (7.5-9) Good (6-7.5) Fair (below 6) Poor (below 6)
| **Synthesis** | The student brought together ideas around a thesis to create a meaningful, coherent essay. In addition, the student placed the topic in an appropriate context and/or made relevant connections to other events, people, places and things. | The student brought together ideas around a thesis to create a meaningful, coherent essay. However, sufficient context is lacking and/or connections made to other events, people, places and things are somewhat strained. | The essay contains satisfactory factual and conceptual content, but is presented in a disjointed, “grocery list” fashion. Moreover, the essay lacks context and/or a clear connection to other events, people, places and things. | The student has failed to construct a coherent essay built around an identifiable organizing theme or concept. |
| **Vocabulary/ Rhetoric** | The student has combined the effective use of subject-specific terminology with vocabulary and variety in expression superior to this grade level. | The student has combined the effective use of subject-specific terminology with vocabulary and variety in expression expected at this grade level. | The student has either demonstrated vocabulary and variety in expression below this grade level, or failed to use subject-specific terminology effectively. | The student has utilized a vocabulary with little or no range and/or no variety in expression. |
| **Mechanics and sentence structure** | The student consistently uses correct grammar, syntax, spelling, punctuation, and capitalization. | The student has an average of fewer than 3 errors per page in grammar, syntax, spelling, punctuation, and capitalization. | The student has an average of 3 or 4 errors per page in grammar, syntax, spelling, punctuation, and capitalization. | The student has an average of more than 4 errors per page in grammar, syntax, spelling, punctuation, and capitalization. |
| **Form** | The student has organized ideas into coherent paragraphs with smooth transitions. The assignment has good structure and unity. | The student has organized ideas into coherent paragraphs, but transitions are sometimes awkward, and/or the assignment does not always hold together. | The student has written with good overall structure and unity. There is weakness in one of the following criteria: organized paragraphs or smooth transitions. | The student has not demonstrated an understanding of paragraph structure, transitions, or unity. |
**Research (if applicable)**

| The student has used a wide variety of informative and relevant sources, and integrated them seamlessly into the body of the project. | The student has used a sufficient number of sources and integrated them effectively into the body of the project. However, one of the sources was of questionable relevance or quality. | The student has provided sources but had difficulty integrating them effectively into the body of the project. Moreover, one or more of the sources was of questionable relevance or quality. | The student has failed to provide sufficient relevant sources for this assignment and/or failed to adequately incorporate outside sources into the body of the project. |

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**Do’s and Don’ts Lists:**

From this work, the following do’s and don’t list was generated.

- The students had difficulty in defining the problem initially as some couldn’t comprehend the independent and dependent variables and defining function. This can be avoided by enforcing a clearly defined proposal at the beginning.

- The project selected should focus on the application of materials learned throughout the program to solve multi-faceted problems such as those they would encounter in the students’ post-academic future employment. The capstone projects typically are narrowly focused and hence they do not cover a wide ranging subject matter. Hence the selection of the project must be given great care so that the project does not become a simple assignment.

- The projects selected must be easy to comprehend, however, should provide opportunities to apply concepts from many courses and develop critical thinking and analytical skills.

- Typically, students select their team members for capstone project. Having worked as a team with colleagues in their classes, one could assume the presence of positive team dynamics. This was found to be the most critical issue for completing the projects on time. In addition, good students join together to form teams leaving behind other students requiring more support. A skill matrix of all students may be developed to assist students in forming teams.
The ‘front end’ project plan and the ‘back end’ documentation and presentation are both important elements. Many team members lacked good report writing skills and as a result, additional help had to be provided. The writing courses taken during the program appeared to be insufficient to write a large report. In addition, constant pressure has to be exercised to get the written part done with the completion of each chapter work.

Since all issues relevant to the project were known to the students at every phase of this project, there were no surprises. The students were given periodic feedback on their work. The students’ enthusiasm was high due to the support provided by the project advisor, instructor, lead faculty, and sponsors. Most of the teams completed their work as per the schedule by incorporating very innovative design. As a result, one of the student teams applied for a provisional patent for their design. This work serves as an example to future participants as a way to maximize their learning potential.

Care must be exercised to make sure
- the selected projects are doable within the time period
- adequate data is readily available
- the project is in the area of manufacturing design engineering
- the project does not depend on one student.

The capstone process exposed some of the deficiencies in the program including materials covered, instruction and instructors. Integrating a project based assignment for the entire program duration would benefit the students in understanding how a final capstone project has to be done.

References:


