AC 2012-5442: A REVISED APPROACH FOR BETTER IMPLEMENTATION OF CAPSTONE SENIOR DESIGN PROJECTS

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Abstract

Primary expectations from a Senior Design Project is defined by ABET with an emphasis on product, process, and professionalism. In principle, the requirements for a senior design project should include development of student creativity, use of open-ended problems, development and use of design methodology, formulation of design problems, alternative solutions, and detailed system description. Constraints such as economic factors, safety, reliability, ethics, and social impact should also be included.

However, it is debated how the process and/or the design product should be assessed, and how the teams should be formed and function for successful project execution. At the School of Engineering (SOE) of the College of New Jersey (TCNJ), the best practices for promoting senior project quality and evaluating quality is an ongoing process and effort and such practices are continuously reviewed, evaluated, and improved. The SOE's efforts and most recent approach and revisions to promote *project quality* and *evaluation practices* for capstone senior design project activities are presented.

The elements emphasized and adopted uniformly by the SOE to promote *project quality* included: a) early involvement of the students (in junior year), b) introduce projects with real-world engineering design problems encompassing considerations of sustainability and investigation of design alternatives, c) multi-disciplinary topics, d) final presentation to a wider audience for added pressure, e) teams of at least three (and preferably four or five), and f) each individual team member budgeting about 150 hrs of time during a semester and keeping a log book with time entries. In addition, scheduled deliverables, periodic status reports, periodic self assessments by the team members are emphasized and the teams are to maintain their respective project webpages. The design and analysis course offering (finite element analysis) was moved to earlier in the curriculum so that the students can make the best use of the modern analysis tools, and come up with more reliable/optimized designs. In case of multi-disciplinary projects, students need to have an advisor from their respective program. The elements emphasized and

adopted to promote *project evaluation* practices include periodic review of journal/log book entries, presentations, periodic milestone reports, at least weekly meetings with the advisor(s), and the final design report.

Introduction

Due to its culminating nature, the senior design project course is probably the most significant experience of the undergraduate engineering students (1). In the process the students apply what they have learned in their undergraduate course work; develop their communication, interpersonal, project management, and design skills; and learn about the product development process. Students also get an understanding of the economic, financial, legal, and regulatory aspects of the design, and development. The capstone design process has the potential to significantly influence the way engineering students think about technology, society, themselves, and the world around them. Students work on teams which help them value diversity and different opinions and perspectives.

There has been an increased emphasis on professional skills to meet the needs of industrial employers (2). This led to an emphasis by ABET on the demonstration of technical as well as professional skills by engineering students via Engineering Criteria (EC) 2000 (3). This is a necessary precursor for university accreditation (4). Primary expectations from a Senior Design Project is defined by ABET with an emphasis on product, process, and professionalism. In principle, the requirements for a senior design project should include development of student creativity, use of open-ended problems, development and use of design methodology, formulation of design problems, alternative solutions, and detailed system description. Constraints such as economic factors, safety, reliability, ethics, and social impact should also be included.

The increased enrollment in the Senior Design project course at the School of Engineering (SOE) at TCNJ led to seek alternate ways for effectively coordinating and conducting the course. In addition, the best practices for promoting senior project quality and evaluating quality were reviewed, evaluated, and adopted.

In this paper, ideas for how to (re)structure the school wide senior project course offerings, assessment process and/or the design product, and how to form teams for successful project execution are discussed. The SOE's efforts and new approach and revisions to promote *project quality* and *evaluation practices* for capstone senior design project activities are presented.

Methodology

The following changes were adopted by the SOE for effective coordination of the Senior Design project course among four engineering departments (of Mechanical, Civil, Electrical and Computer, and Biomedical). These were made in response to the increased enrollment in the Senior Design Project Course.

Senior Project Course Coordination

In order to enhance interaction between faculty, students, machine shop operators, and external sponsors, departmental coordinators for the senior project course were instituted, thereby decentralizing the course structure. These coordinators (one from each engineering department) replaced the existing school-wide senior project coordinator and, among others, perform the following tasks:

a) Coordinate BME/CIV/ELC/MEC 495 and 496 (senior design project class),
b) maintain a list of available, current and past projects through Senior Project web site,
c) maintain evaluation data and manage presentation to ABET,
d) schedule oral presentations,
e) finalize project grades utilizing advisor input,
f) place students (in coordination with department chair) with unsuccessful project proposals, and
g) serve as a liaison among faculty, students, machine shop operators and external sponsors.

The departmental coordinators regularly meet and discuss methods to improve the senior project experience as well as maintaining fluid interaction between participants in different majors. These interactive meetings help constantly reevaluate the effectiveness of the senior project experience and the evaluation process.

The suggested number of class meetings for departmental coordinators is as follows:

- For Senior Project I a minimum of 7 meetings (fall semester),
- For Senior Project II a minimum of 4 meetings (spring semester),
- For Senior Project Seminar a minimum of 3 meetings (spring semester).

Number of meetings listed above does not include student oral presentations (3 in the fall semester and 1 in the spring semester) or coordination meetings (suggested minimum 2 per semester).

Benchmarking

The elements of best practices employed at peer institutions for promoting quality, and assessment in senior design projects are presented together with possible actions to be considered for enhancing existing senior project process. The following aspects for promoting project qualities were adopted:

1. ***Early Involvement***

   It was hypothesized that getting the students involved earlier would yield improved project quality. For that matter:

   a. Engagement of students starting in junior year has been introduced. Now, students are required to seek their senior project proposals approvals by the end of their junior year. In this manner, students get all of the summer time to build upon their preliminary concepts.
   b. Attendance in the senior design project presentations is mandatory for the juniors.
      i. A *Senior Project Seminar* class has been introduced *(Fig. 1)*. This is a zero credit class, scheduled in spring semester of the junior year, a prerequisite to the senior design project class, and is graded as pass / fail.
      ii. The students are expected to *develop proposals* and *seek for faculty advisor(s) (willing to sponsor their project)*, and submit a *signed proposal form* to receive a passing grade.

iii. Students are required to formally present their proposal to the SOE Faculty during the first or second week of Senior Project-I class. The process involved in SP-I and SP-II are also outlined in *Fig. 1*.

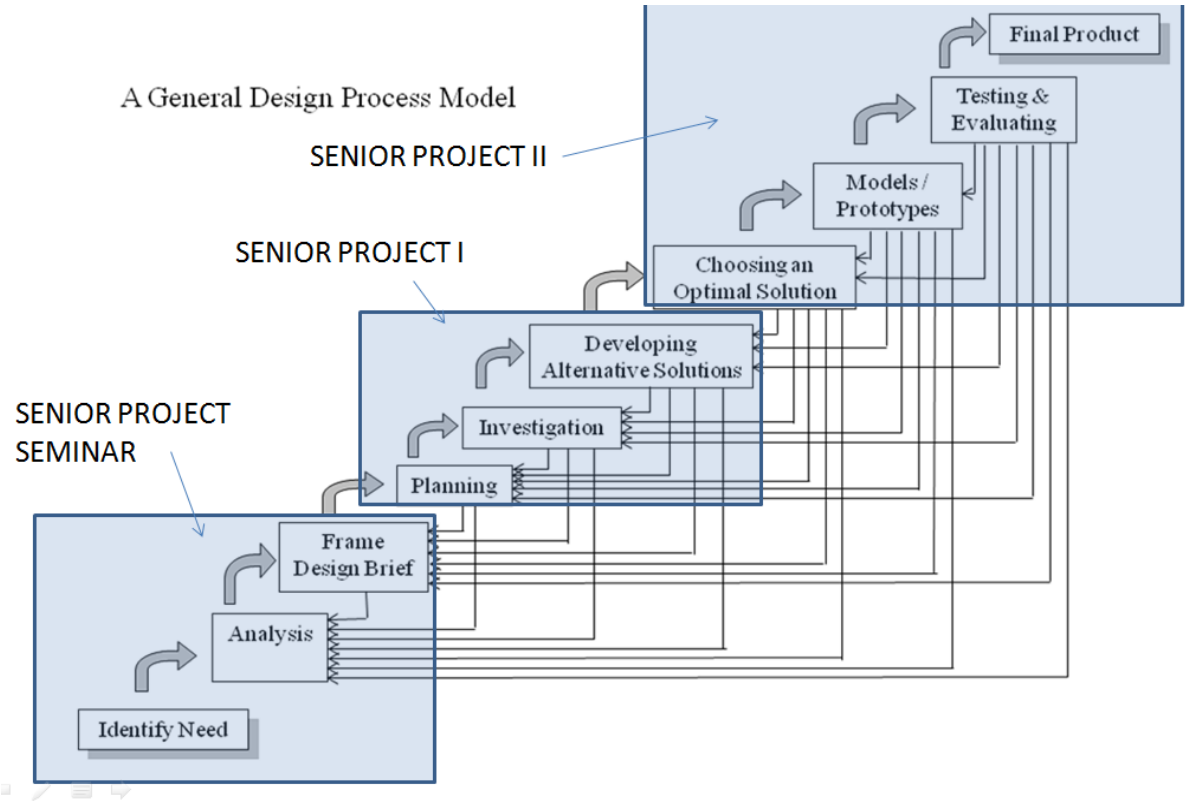

Fig. 1: The Required Processes and the Milestones for Start and Completion of a Culminating Senior Design Experience at TCNJ.

2. Wider audience

It has been realized that the added pressure of a wider audience for senior project presentations helps to motivate students to do their best (5). For that matter, members of the Industrial Advisory Council, industry advisors and other guests are invited to attend senior design project presentations. In addition, all projects are now required to have an online presence. The links to all current senior design projects are available on the SOE website. These steps may also help in promoting the ownership of the projects yielding a better quality output.

3. ***Real-world engineering design problems***

Real-world engineering design problems are now given priority for getting approved as a senior design project. In addition, multidisciplinary and interdisciplinary projects and team work are being promoted. Considerations of sustainability and investigation of design alternatives are emphasized.

4. ***Design project teams and selection***

The formation of student teams for senior design projects is critical to the success of the design project and the course experience (6). For the project to be successful the students should be motivated and enthusiastic about the project. In addition, the student members should also possess the necessary skills (technical or academic) required for the individual project. At SOE, in addition to considering student preferences in the team formation process and careful assessment of student strengths and weaknesses, team size of at least three students (preferably four or five) has been found to be more effective. The work load of each student should be such that each student must log in a minimum of 150 hours of work each semester.

5. ***Curriculum change***

The computer aided design and analysis course offering (finite element analysis) was moved to earlier in the curriculum so that the students can make the best use of the modern engineering analysis tools, and come up with reliable modes that may lead to optimal/sound designs. Since its implementation, the application of the modern engineering software has seen a multifold increase.

The following aspects for promoting project evaluation practice were adopted by the SOE. The project teams are evaluated periodically as following:

- **Proposal Review (**scheduled during week #2): Proposal evaluation is based upon the teams' presentation to the faculty. The faculty critiques and examines the *"Degree of Difficulty and Feasibility"* of the project and makes suggestions.

- **Preliminary Design Review** (scheduled during week #10): Evaluation is based upon the teams' presentation to the faculty. Again, the faculty critiques the project and makes deeper inquiries.

- **SP-I Final Design Review:** Evaluation is based upon the teams' presentation to the faculty (scheduled during week #14), and submission of the Senior Project Design Report –I (during week #15 of the fall semester), meeting (the promised) milestones of the project and the progress made towards the completion of the design phase.

- **SP-II Final Design Review:** Evaluation is based upon the teams' final presentation to the faculty (scheduled during week #14 of the spring semester), completion of the fabrication requirements [and (if applicable) fully tested for presentation or regional/national competitions], and submission of the Senior Project Design Report –II (during week #15 of the spring semester).

- **Periodic log book review** (bi-weekly): Students maintain design journals which are periodically evaluated.

- The grading rubrics for SP-I (Table 1) and SP-II (Table 2) were developed and adopted.

Forming a Senior Project Team and Improving its Chances of Success

Tables 3 and 4 together provide a summary of the essential elements and stages of team development as well as some suggestions for planning and improving the chances of success for a team based project (7).

Conclusion

The efforts of a group of faculty at the School of Engineering of the College of New Jersey were shared with the engineering education community. This new approach and revisions for promoting *project quality* and *evaluation practices* for capstone senior design project activities were presented. Engagement of students with their senior projects starting in the junior year has produced promising results. Junior students are required to identify their senior project, form

their team and obtain the sponsorship of a faculty advisor by the end of their junior year. They are encouraged to choose real-world engineering design problems as their senior design project. Multidisciplinary and interdisciplinary projects and team work are being promoted. Incubation effects during the summer period, and voluntary or accidental research/discoveries has added to the momentum of the teams of students for challenging their senior projects. Calibration of the time of offering of certain courses (including the finite element analysis course) has shown positive impact on the quality of the projects. The fruits of the newly adopted system are already visible through the enhanced quality of this year's projects. A longitudinal assessment of the changes will be made in the coming years.

Acknowledgement

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Bibliography

1. **Goldberg, Jay R.** *Capstone design courses producing industry-ready biomedical engineers.* CA : Morgan & Claypool Publishers, 2007.

2. *The ABET "Professional Skills" – Can They Be Taught? Can They Be Assessed?* **Shuman, Larry. J., Bestterfield-Sacre, Mary and MCGOURTY, Jack.** 2005, Journal of Engineering Education, pp. 41-55.

3. *Effective engineers.* **Newport, C.L. and Elms, D.G.** 5, 1997, International Journal of Engineering Education, Vol. 13, pp. 325-332.

4. *Quality Assurance for Engineering Education in a Changing World*.* **Philips, W, Peterson, G. and Aberle, K.** 2, 2000, International Journal of Engineering Education, Vol. 16 , pp. 97-103.

5. *CS Capstone: Lessons from the Field.* **Adams, R. and Alsabbagh, J.** Colorado : Capstone Design Conference , 2010.

6. *Development of High Performance Capstone Project Teams and the Selection Process.* **Laguette, S.** Colorado : Capstone Design Conference, 2010.

7. *Valuable Lessons from the Successes and Failures of Teams of Engineering Students.* **Sepahpour, Bijan,** Proceedings of the 2005 ASEE Conference, Portland, Oregon.

Tables

Table 1: Proposed Senior Project-I Grading Rubric (note that percentages are proposed minimums)

Topic	% (min)	% (actual)**	Grading	T/I*	Comment
Project Proposal	5%			T	Identify Need, Analysis, and Frame Design Brief (as well as Presentation Technique)
Preliminary Design Review	5%			I	Planning, Investigation, and Alternative Solutions (as well as Presentation Technique)
Final Design Presentation	10%			I	Final Design, Documentation, Presentation Technique
Project Planning	5%			T	Budget, Schedule, and Gantt Chart
Final Design Report	10%			I	Content, Organizations, Format, Style
Technical Merit	10%			I	Innovation, Complexity, Execution, Degree of Difficulty, Quality
Contribution to Project	10%			I	Peer Review & Notebook; Evaluated by faculty advisor

* T = Team Grade, I = Individual Grade

** Advisor(s) and student(s) should agree upon and fill in actual percentages before submission of proposal

Table 2: Proposed Senior Project-II Grading Rubric (note that percentages are proposed minimums)

Topic	**% (min)**	**% (actual)****	**Grading**	**T/I***	**Comment**
Testing / Validation Plan	5%			T	Effectiveness of Testing / Validation Process
Testing / Validation Execution	5%			T	Overall Success of Testing, Data Collection, Readiness for Competition and / or Presentation
Project Planning	10%			T	Cost / Benefit Analysis, Schedule, Critical Path Network
Final Design Presentation	5%			I	Final Design, Documentation, Presentation Technique
Final Design Report	10%			I	Content, Organization, Format, Style
Technical Merit	10%			I	Innovation, Complexity, Execution, Degree of Difficulty, Quality
Contribution to Project	10%			I	Peer Review & Notebook; Evaluated by faculty advisor

* T = Team Grade, I = Individual Grade

** Advisor(s) and student(s) should agree upon and fill in actual percentages before submission of proposal

Table 3. Suggestions for Advisors in Planning the Project.

Essential Elements of Team Development

- *Positive Interdependence*
- *Face-To-Face Promotive Interaction*
- *Individual Accountability/Personal Responsibility*

These elements form the transformation process that converts a group of individuals into a fully functioning, cohesive group.

Stages of Team Development

- Forming
- Storming
- Norming
- Performing

The goal is to get to the PERFORMING stage as early as possible.

Planning the Project - Team Formation and Setting the Expectations

1.	Evaluate the feasibility of conducting the project with regard to its required finances, human resources, equipment, facilities, deadline for completion, etc.
2.	Recruit members that their interpersonal and intellectual skills complement each other.
3.	Set realistic expectations and challenge each of the members at a level that they may succeed.
4.	Prepare a preliminary timetable for major activities involved in the project.
5.	Establish a clear grading policy that is consistent with project's objectives and its requirements.

Table 4. Suggestions for Improving the Chances of Success for a Team Based Project.

Suggestions for Advisors to successfully Implement Senior Projects	
1.	Plan a comprehensive first meeting, reviewing all objectives, rules and regulations and logistical issues related to the project.
2.	Review the role of each member as an individual contributor and make it clear that the success of the team depends on the performance and dedication level of each of the members.
3.	Provide sources of information for conducting research and obtaining related literature.
4.	Inform the new team about the existing network of support for obtaining financial and professional assistance.
5.	Discuss the synergistic nature of the design and team work activity and provide examples of success and failure using prior experiences, etc.
6.	Set up a regular weekly time for group meetings that is compatible with every member's schedule and emphasize on the importance of participation of all members.
7.	Make them aware that a later change of design in one of the components/subsystems of the product may create a "Domino Effect" on many other components/subsystems.
8.	Have the entire team work with the project manager to generate a Gantt chart and a Critical Path Network.
9.	Have all members provide a progress report on weekly-basis and discuss/brainstorm the potential solutions for the newly encountered/unforeseen problems.
10.	Encourage members to finalize a (seemingly) flawless and promising design before they start fabrication.
11.	Encourage/require the team to test the functionality/practicality of their proposed designs by computer simulations and actual prototyping.
12.	Establish ample hours for the project, and make yourself available for all team members.
13.	Have the entire team make a presentation to previous year team members and all involved supporting individuals/collaborating advisors at critical stages of the project.
14.	(If applicable,) Encourage the previous year team members to provide support and advice for the young/inexperienced team.
15.	Establish a rewarding and appreciation system for all the parties involved.