AC 2008-1045: IMPROVING THE QUALITY OF SENIOR DESIGN PROJECT REPORTS

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Improving the Quality of Senior Design Project Reports

Abstract

The ME-EM Design Committee at Michigan Tech recommended in early 2007 that the capstone design course emphasize that student teams produce quality project reports. This paper presents the steps taken during fall 2007 to meet this objective. Several problems were addressed:

- ***Class size:*** A total of 106 traditional capstone design students were signed up for the class; they were organized into 21 project teams for two semesters, producing 63 reports. Shortly before the start of the class, 42 mechanical engineering seniors in the enterprise program were added for one semester. These students were not part of project teams with classmates and thus were anticipated to generate 126 additional reports—a logistics nightmare.
- ***Unfamiliar thinking skills:*** The thinking styles assessment of the entire class showed they had a low average in the thinking preferences required for communication and teamwork. Thus learning how to write good reports would require extra effort by the students.
- ***Expectations:*** Many of the enterprise students did not see the need for having to take this class, since they had already been involved in their enterprises for two or three years and believed they knew how to write reports. Other students expected this to be an easy course. Both sets of expectations affected their attitude towards learning, applying the design tools taught, and communicating the results.

The three required project reports—project proposal, progress report, and end-of term report—were evaluated as follows: (a) The class instructor checked that the design tools and models taught in the course were applied correctly; (b) The project advisors evaluated the technical merit and progress of the project work; (c) A technical writer was hired to edit the writing, check for correct format, and verify that students implemented the suggested revisions.

The addition of the enterprise students provided an unplanned control group and revealed different results for report grades based on writing, format, and use of design tools:

Type of Report	*Enterprise: Average*	*Range*	*Capstone: Average*	*Range*
Project Proposal	93%	76-100	92%	80-98
Progress Report	80%	50-102	89%	73-98
End-of-Term Report	82%	60-98	90%	84-96

Two factors of concern were identified: (1) about half the capstone project teams did not apply adequate engineering analysis to their designs; (2) many students in the class did not read and follow instructions for preparing and revising their reports or use outside sources of information. It was discovered that the presence on the capstone design project teams of at least one student with strong preferences of thinking skills required for communication and teamwork correlated with higher report grades. Other conclusions and recommendations include: providing a technical writer (and report templates); just-in-time teaching and application of design tools; building the skills needed for conceptual design and open-ended problem solving in the engineering curriculum in stages over four years; and having a departmental panel review the end-of-term reports and require additional work for removing deficiencies before giving a go/no go recommendation to the instructor to allow the teams to continue with their project.

Introduction

The ME-EM Design Committee at Michigan Technological University in early 2007 increased its demand that graduating mechanical engineering seniors (through the capstone design course) produce quality project reports: (1) project proposal, (2) progress report, and (3) end-of-term or final report. This paper describes the evaluation process, as well as the resources needed for this effort in a large class composed of the two different types of students during fall 2007. Based on the experiences and results, recommendations are given that should enable project teams write higher-quality reports.

Over the past decade, the emphasis in the capstone design course has moved from "drafting" using 2-D and 3-D software to a much broader view of design defined as

Engineering design is the communication of a set of rational decisions obtained with creative problem solving and engineering analysis for accomplishing certain stated objectives within prescribed constraints.

Although guidelines and practice were also provided on how to deliver quality oral presentations, this paper focuses on the writing of quality technical reports.

Problems and Constraints

a. Class size and types of students: A total of 106 senior capstone design students were signed up for the class, and they were organized into 21 *balanced* project teams according to abilities and thinking style for two semesters. Shortly before the start of the first semester, 42 mechanical engineering seniors from the enterprise program were added to the class for one term. The instructor was told that these "enterprise" students had to be treated exactly the same as the capstone design students, even though they were different (as summarized in Table 1 and discussed in the following section).

Table 1 Differences in the Two Student Groups

	MEEM 4900-Capstone Design	***MEEM 4990-Enterprise***
Course Format	2 Semesters	1 Semester
Autonomy	Independent projects	Sub-projects
Team Size	4 to 6 students	From 1 to 3 students in class
Team Formation	Based on HBDI, project needs	Working in large enterprise teams
Team Development	Closely monitored; leader seminars provided	Multi-disciplinary, multi-level; monitored by enterprise advisors
Project Topic Scope	New, challenging, important	Significant to trivial
Design Focus	Structured through entire process	Partial to no design content
Project Sponsors	Industry or faculty projects	Primarily their enterprises
Design Tools: Pugh Method, QFD, FMEA, DFX, etc.	Integral to conceptual design, development of alternatives, and optimization	Poor fit of tools with stage of most projects (except for decision making using Pugh method)
Entrepreneurial Focus	Applicable to consumer products	Not as strong as expected

Capstone students go through the traditional mechanical engineering curriculum, and during their final year, they complete a two-semester capstone design course (3 credit-hours each semester). This course consists of two class-hours per week the first term and one class-hour per week the second term. In addition, students have to apply class learning (the design process and design tools) with engineering analysis to a real-world sponsored team project requiring on the average at least four hours of work per team member per week. ***Enterprise students*** sign up for the multi-disciplinary enterprise program in the sophomore year, either as a 12-credit enterprise concentration option or a 20-credit enterprise minor. This program was envisioned to give teams of students the opportunity to run their enterprises for solving engineering problems supplied by industry partners.[1] Unfortunately, not all enterprise teams achieve these educational goals, since the quality of their learning is strongly linked to the scope of the chosen enterprise project, the selection of enterprise course electives, the supervision and grading standards observed by their advisors, and the students' motivation and initiative. The Mechanical Engineering-Engineering Mechanics (ME-EM) Department administration became concerned that some of the enterprise students were graduating without the solid design skills that their graduates should have under the requirements for ABET accreditation. This concern motivated the addition of the enterprise students to the first semester of the rigorous capstone design course.

b. Unfamiliar thinking skills: The Herrmann Brain Dominance Instrument (HBDI)[2,3] was used to obtain the thinking styles profile for each student in the class. Figure 1 summarizes the characteristics of each of the four distinct thinking styles of this model.

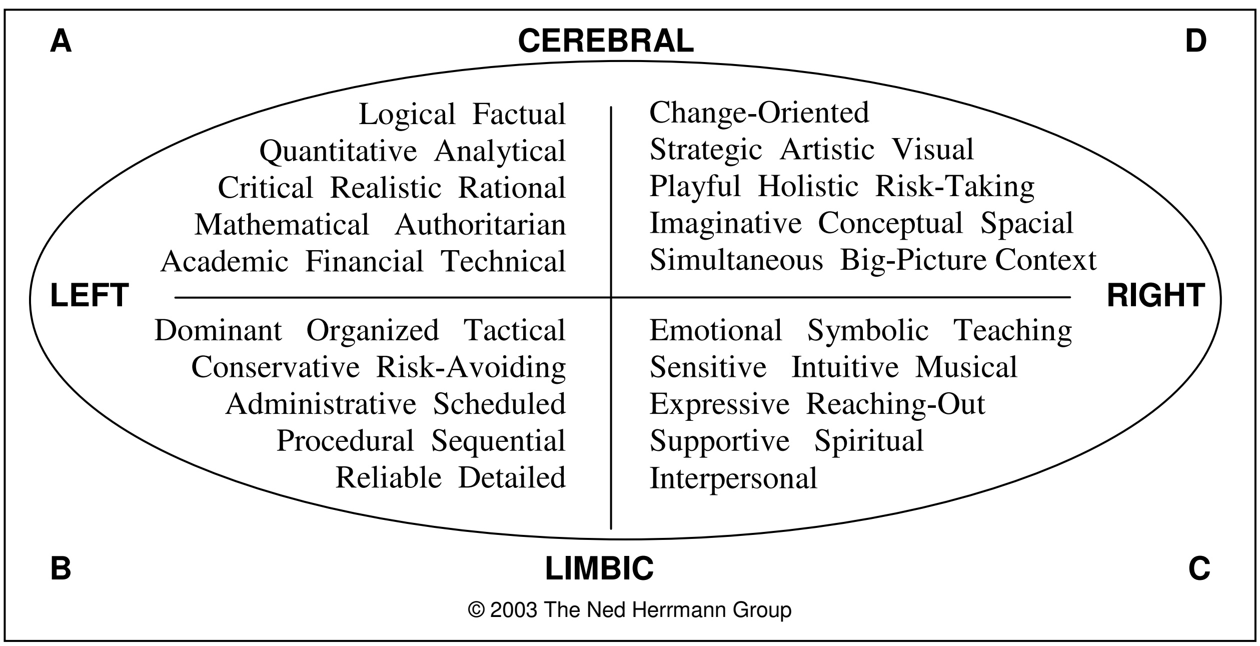

Figure 1 Thinking characteristics and behavioral clues of the four-quadrant Herrmann model of brain dominance (HBDI)

As is typical for engineering students, the HBDI results for both the enterprise and the capstone students showed that they had a low average in the quadrant C thinking preferences required for communication and teamwork. Twenty-two (or 21%) of the capstone students and eight (19%) of the enterprise students had scores that indicated a preference so low that it would be akin to discomfort with or an avoidance of quadrant C thinking modes. Thus, good report writing would require extra effort by the students and extra attention and encouragement by the instructor and the project advisers. Also, contrary to the goals of the enterprise program (and our assumptions), we found that the enterprise students on the average scored lower in quadrant D, the preferred thinking mode of entrepreneurs, than the mechanical engineering students in capstone design, at 66 versus 70. A score ≥ 67 indicates a strong preference, a score between 33-67 comfort in usage, and a score ≤ 33 a tendency to avoidance.

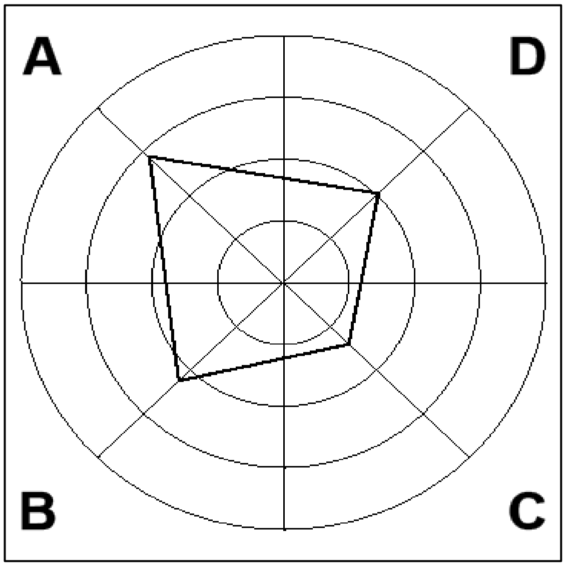

Figure 2 Average HBDI profile of class (A=96, B=75, C=47, D=68)

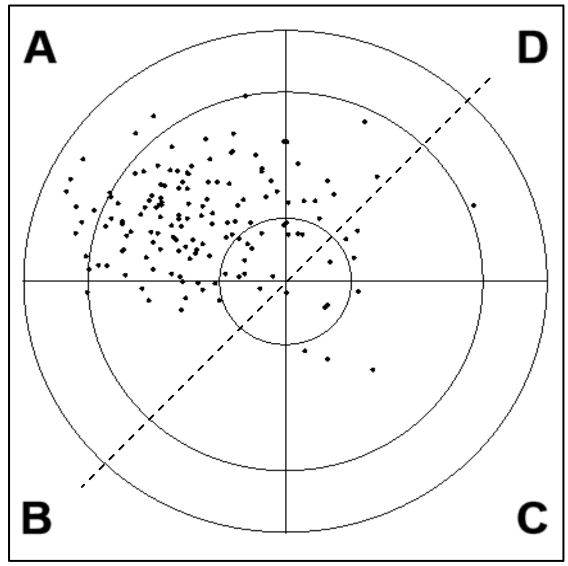

Figure 3 Preference map (HBDI profile "tilt") of 148 engineering students

We have used the Herrmann Brain Dominance Instrument (HBDI) for nearly 20 years to form mentally balanced project teams.[4-8] In such teams, the students learn to communicate and work with people who have different thinking preferences—which in turn is conducive to achieving optimal problem solving results.[9] Although it is expensive, there is simply no better tool for this purpose, as concluded by the extensive Coffield report[10] which compares thirteen models of learning styles used in the UK. Forming balanced teams with engineering students is not always possible, because by the senior year, very few have a "tilt" for quadrant C thinking (as shown by the dots in Figure 3 to the right of the dashed line) or scores in quadrant C ≥ 67. Also, when teams are self-selected, they tend to be imbalanced, because most people prefer to work with others who have similar thinking preferences.[11]

c. Student expectations: Many of the enterprise students did not see the need for having to take this class, since they had already been involved in their enterprises since their sophomore year and believed they knew how to write project reports (as well as many of the other objectives of the course, such as the structured design process and specific design tools). Some of them resented the change in requirement, since they had chosen the enterprise track to avoid the capstone design course. On the other hand—based on feedback from former students—many capstone design students expected this to be an easy course with few demands. These expectations affected the students' attitude towards learning, applying the design tools taught, and communicating the results in quality reports.

Course Organization and Report Evaluation

Right from the start, it became obvious that the two groups of students could not be treated or graded the same way. The capstone students were formed into their balanced project teams under the supervision of the class instructor before the start of class and could immediately start to work on an assigned sponsored project while periodically checking in with their advisor, a mechanical engineering faculty member. The enterprise students, on the other hand, were involved in large enterprises with up to 30 students. These were then split into smaller multi-disciplinary and multi-level teams to work on sub-projects, where the design, development, evaluation and optimization phases of many of the enterprise projects extend over several years. Figure 4 shows the organization chart with the different stakeholders for the class.

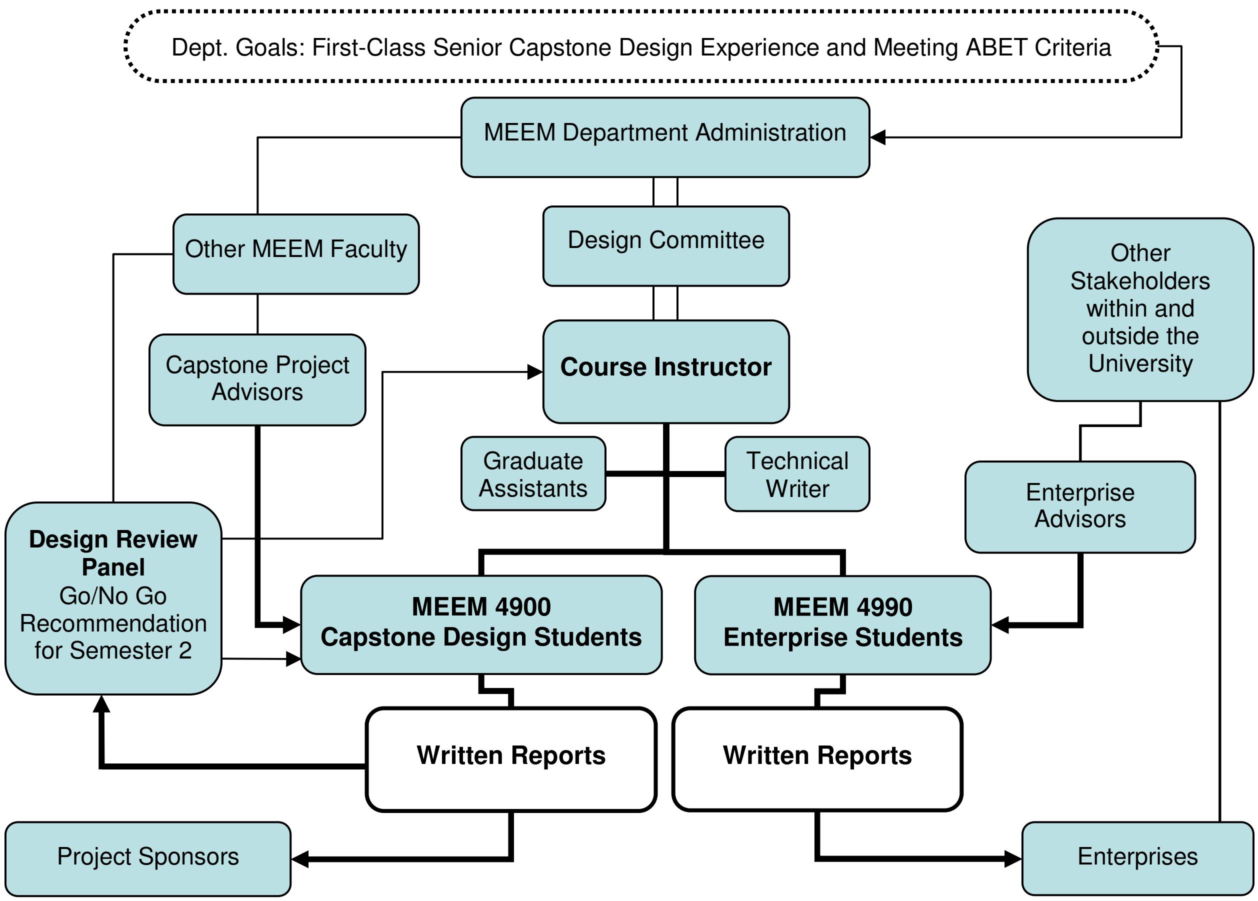

Figure 4 Stakeholders and Organization Chart for Capstone Design Class, Fall 2007

The first problem to be solved was to get the cooperation of the enterprise advisors in several engineering and technology areas to help monitor the progress of the enterprise students that were in the design class. First, the advisors were informed with a detailed handout packet about the class requirements. Then a planning meeting was organized, and the group discussed how the progress of these students could best be monitored so they would meet these requirements within the context of their enterprises. The advisors were very concerned that their workload (and that of their students) not be unduly increased. Later, one advisor refused outright to participate.

Because the enterprise students had to apply class learning to a project related to their enterprise and document this learning in three reports, we wanted to quickly form them into project teams by enterprise. But we had to change this plan after we collected feedback from the students on their involvement in their particular enterprise projects. It took five weeks and careful evaluation of their project proposals before these students were finally organized into three teams with three students, eight teams with two students, and 17 students reporting independently on a subproject of their choosing (although they were working with other students in their enterprises and allowed to include that work in their reports if properly acknowledged). This reduced the number of reports that had to be graded in the class from 189 to 147—still an unmanageable amount for one instructor to handle. In response to this need, a technical writer familiar with the course content was hired. But because the enterprise students could not be assigned to balanced project teams, they provided an unexpected control group for comparing class results.

Grading

The departmental objectives for the students' capstone design experience were to far exceed the ABET Criteria 2000 considered to be the floor, not the ceiling, for content and quality. Although the enterprise students would be taught the same class content, they were not held accountable and monitored for learning and applying it in their projects to the same degree as was possible with the capstone design students. The class instructor graded the written reports for all students, as well as the oral presentations and posters of the capstone design students, based on correct application of the design models and the design and communication tools taught. The advisors supervised and graded the technical merit (engineering analysis) and progress of the design projects, as well as the design journals. The enterprise advisors were also responsible for grading oral presentations and posters—these could not be monitored by the instructor due to time constraints. As a result, the enterprise advisors had a larger influence on the final course grade than the capstone design advisors. Therefore, this report will only compare the performance of the two student groups based on the evaluation of the three major reports and excluding the advisor's points for technical merit.

The largest hurdle for evaluating the application of learning in the enterprise student reports was that their projects were at various stages of development, from initial problem definition and conceptual system design to part design and optimization, prototyping, and testing. The students with small subprojects seemed to work in isolation, with little influence on the direction of their enterprise as a whole, even when they had learned tools that could have improved the quality of their entire project—because these were not available "just-in-time." They needed much help to identify areas where they could apply at least one tool—the Pugh method—if not for generating creative design options, then at least to help them make design decisions based on a rational set of criteria and not arbitrarily or by a process of trial and error.

The technical writer edited the reports and checked for correct format and template use to help students improve the writing quality (grammar, spelling, style). Well written reports took from 30 to 45 minutes to proof-read and edit. Many of the poorer reports took from 75 to 90 minutes, and a few up to three or four hours—these were from enterprise students, and some of these had to be regraded after major revisions were made by the students. Two doctoral students assisted with managing the course materials, distributing handouts, collecting and grading some of the homework, and posting all course materials and lecture slides on WebCt.

Capstone Design Review Panels

The Design Committee developed a structure for reviewing the progress of the capstone design projects, based on a written end-of-term project report and a 10-minute oral presentation. Although the course instructor did not like this panel review in the beginning, since he saw it as usurping his authority to grade the students' performance in his course, a compromise was reached: the design review panels could make recommendations to the instructor on a go/no go decision about allowing a team to continue on to Semester 2 work. The main function of the panel was to require teams to do additional work to remedy identified deficiencies during Christmas break. Each panel also graded the team's oral presentation. This was accepted by the instructor and accounted for 5% of the course grade. Benefits of this design panel review are:

1. The go/no go review mirrors a process used in industry and gives the students valuable experience.
2. Each review panel was composed of two different faculty members (not project advisors) and one doctoral student. These panels provided an outside judgment of the students' work (based primarily on an in-depth scrutiny of their end-of-term report).
3. The panel review identified a deficiency in approximately half the design teams—mainly, these students had not applied appropriate or necessary engineering analyses they had been taught in their previous course work.
4. The final project outcomes (and final reports) in a previous capstone design class were found to be of high quality—since the design review inspired students to increase their efforts to complete their projects well during the second semester.
5. The panel review also provides valuable input to advisors on their role of monitoring their projects (some of the advisors were new arrivals on campus or had no previous design or advising experience).
6. Serving as a panel member involves many faculty members and thus increases the overall awareness among the faculty about the innovative approaches of the course.
7. Overall, the panel review members were impressed by the professional quality of the oral presentation skills of the students, including their teamwork.

Report Requirements

Whereas the projects for the capstone students were provided by sponsors, the projects for the enterprise students were determined by the enterprise and approved by their advisor. Since these enterprise projects were at various stages of development, from problem finding and conceptual idea generation to optimization, continuous improvement, and integration into a larger system, these students potentially had an opportunity to apply class learning creatively in many different ways while roughly following the given report formats. Also, the lectures during the last two weeks were different for the enterprise students to provide closure to their course participation.

The required content of the three project reports is shown in Table 2. Students did not need to rewrite the entire report each time, since much of the information from a previous report could flow into a subsequent report with minor updating, with new sections added to report progress made on the project.[5,6]

Table 2   Required Documentation and Information Flow for the Project Reports

Project Proposal	**Progress Report**	**End-of-Term or Final Report**
Cover letter Title page Executive summary	Cover letter Title page Table of contents (optional) Executive summary	Cover letter Title Page Table of contents Executive summary Acknowledgments
Introduction Design problem statement Design constraints User profile and needs Design objectives	} Update and refine all sections to current status	} Condense and update. Include design summary (one-page description & final concept drawing)
	Progress on design decisions: Table and discussion of each (with creative alternatives, decision rationale, engineering analyses, Pugh charts, etc.)	Complete discussion of all decisions made, showing the decision-making process, with concept and design drawings in Appendix. Include DFX, DFM, DFA considerations.
Proposed design evaluation: a. Building/testing prototype? b. Computer simulation? c. Evaluation by experts? d. Performance evaluation by different analytical methods?	} Design evaluation plan: update; include any results available to date	} Design evaluation: Test results Prototyping results Simulations Expert evaluations Analyses (summarize in tables, charts, graphs)
Project plan References	Current status of project plan with Gantt chart Expanded references Appendix with supporting data, drawings, and charts	<u>Enterprise:</u> Final status of Gantt chart; conclusions and recommendations. Final design evaluation by team (how were objectives met?) <u>Capstone:</u> Current Gantt chart; project plan for Semester 2 work. Results of design review and design changes. Discussion of team dynamics. Complete list of references. Appendix with index, drawings, supporting data, and charts.

Resources

Students had many resources available to enable them to produce quality reports:

a. An informational spring meeting was held for the capstone design students, giving an overview of the design course logistics, content, process, and objectives, with brief presentations by the instructor, other course supporting staff, and a design committee member. Students were encouraged to hone their word processing skills over the summer and to study technical reports[5,12] to observe writing style and presentation of graphs and tables.

b. The course textbook[6] includes templates and examples for all important pieces of documentation required in their reports.

c. Several lectures provided tips and detailed guidelines for writing the reports. All lecture slides and handouts were posted on WebCT, so that students who missed a lecture due to interview or plant trips would have all information available.

d. Each report was edited carefully. A summary sheet of tips and errors to avoid was compiled and posted for all students after each review—with a warning that if the same mistakes were made in future reports, points would be subtracted for each occurrence.

e. Failing reports had to be resubmitted for regrading and another round of editing, so students would have a chance to incorporate the improved version into their subsequent reports.

f. Students received direct e-mails to keep them updated whenever previous information was changed and the syllabus was streamlined.

g. The instructor was available to meet with teams by appointment. The technical writer and one of the teaching assistants were available for an hour after class to answer any questions and provide specific help with design tools or writing software.

h. The teaching team was always ready to answer e-mail questions as quickly as possible (except when the answer had already been provided several times in the resources listed above, and the students had no excuse for not having paid attention).

i. The leaders of the capstone design teams (or their alternates) had an opportunity to attend a leader's seminar offered on Saturday every two or three weeks (lunch included). The seminar was a forum for learning principles of leadership, asking questions, exchanging tips for improving the team's reports, as well as resolving a few teaming issues.

Results and Experiences

1. Project Proposal

As the first deliverable, the capstone design students were required to submit a precise project proposal addressed to their sponsor at the end of the third week, incorporating the sponsor's design constraints, a problem analysis, and design project objectives. However, before the proposal could be submitted to the sponsor, it was reviewed by the instructor and technical writer for editing and grading. The purpose of this report was to demonstrate that the project team understood what the sponsor required of them. In a few cases, misunderstandings were cleared up at this early stage, or the sponsor changed some constraints or objectives. The points earned by the capstone design teams for their project proposal are shown in light color in Figure 5.

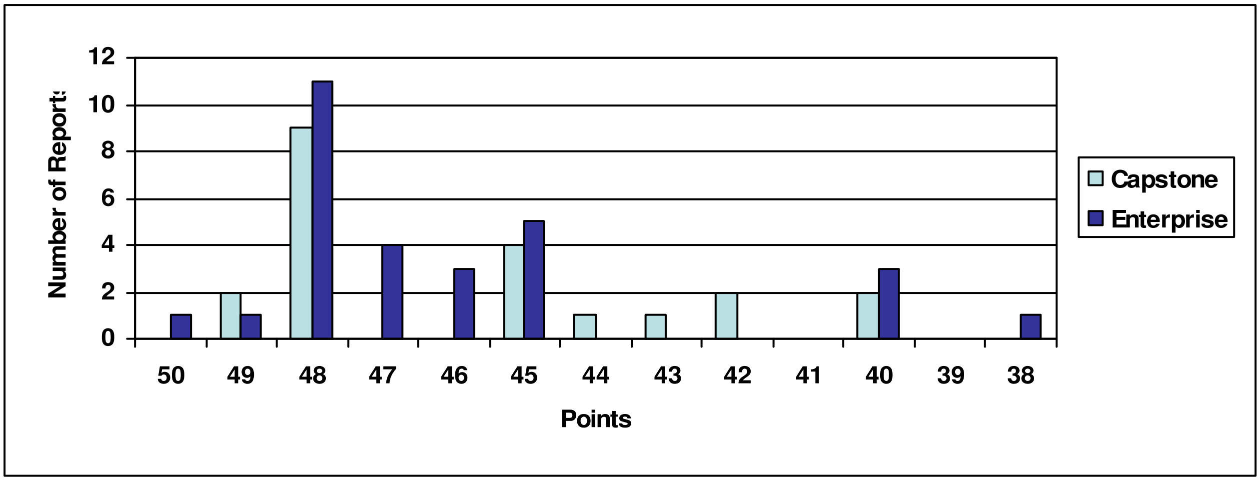

Figure 5   Comparison of Project Proposal Grades for Capstone and Enterprise Students

The enterprise students needed additional time (some of them several weeks), because their enterprises had to recruit new students and identify a problem and subprojects to work on. Also, eleven of the 29 enterprise project proposals were returned after the first round of major editing for extensive revision before they could be graded properly. These students were asked to write the project proposal in two parts, with Part 1 describing the overall scope of their enterprise and their past work in it, and Part 2 outlining the subproject's objectives, constraints, and project plan. Because of this extra work, the enterprise students were given double the points that are shown in Figure 5 for this assignment.

The average of 21 capstone reports was 92%, compared to 93% for 29 enterprise reports. Most of the enterprise students did a good job summarizing their enterprises based on previous team reports. The instructor gained a better understanding of the context that these students faced in terms of projects, teaming, experience, and design phase; it enabled him to suggest that students form teams of two or three wherever possible, to cut down on the number of reports. After all grades were in, two of the students with 40 points decided to team up, and their synthesized proposal earned 48 points. Grading was lenient for these first reports, although the summary of comments with writing instructions to be used in subsequent reports was six pages long.

2. Progress Report

The grading standards were raised as the semester progressed. Reports were downgraded for repeated mistakes. The focus of the progress report was the Table of Design Decisions and the application of the Pugh method for evaluating alternative design concepts. Although examples were demonstrated and discussed in detail, many students did not apply the tool correctly. The enterprise reports without a Pugh method application were returned to the students—with areas in their reports identified where they could use the Pugh method for decision making. These reports were then edited again to give the students a better version to build on for the next report. However, many continued to be careless about making all required corrections, or they turned in reports late. Many showed no signs that they were proof-read or had been spell- or grammar-checked. Punctuation and structuring a simple sentence or paragraph correctly were a problem for some students, as was using a formal (as opposed to a colloquial) writing style. Even writing a simple cover letter proved to be difficult, although they were given a template to follow.

A large difference in performance was found between the capstone and enterprise students, when their progress report grades were compared (equalized to the same total of possible points as seen on Figure 6). Overall, the enterprise average was 80%, the capstone average 89%. Three enterprise reports were excellent—two of the projects were at least of the quality and challenge of a capstone design project (and also a good match in development stage, so the design tools could be applied just-in-time and were thus appreciated). One project topic was creative—this student chose to develop a guide for future team leaders on how to apply the design process and tools properly in their enterprise. The remaining enterprise reports ranged from mediocre to very poor—mostly because the students seemed unwilling or incapable of finding areas where some of the tools taught could be applied. Several enterprise students reported on their trial-and-error design approach used to develop or optimize their designs, with many design decisions made arbitrarily, without documenting the rationale for the decisions made.

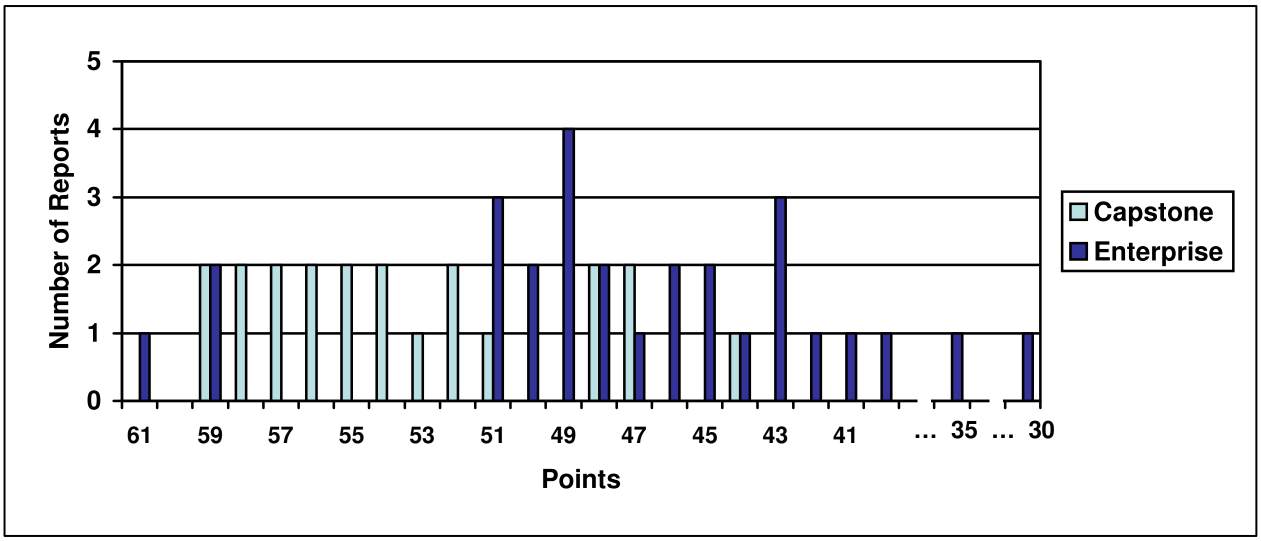

Figure 6 Comparison of Progress Report Grades for Capstone and Enterprise Students

3. End-of Term or Final Report

Although the average (82% for enterprise and 90% for capstone) remained relatively the same, the distribution of the grades changed markedly for the enterprise students. As seen in Figure 7, about one-third of the final reports submitted by these students were very poorly done (spread over seven advisors). The grades ranged from 60 to 98—a difference of 38 points. Five advisors (involving 11 projects) had 19 students producing excellent final reports. The students (one hospitalized) with the four failing reports were given a chance to submit a revision (which upped their scores to 84, 86, and 88, respectively. One student continued to fail (at 69 points), losing points for being late (despite a warning) even after making a few improvements but leaving other deficiencies uncorrected. The report grades in Figure 7 are normalized for comparison with Figure 8. The enterprise students received double points, with an additional 100 points available to be added by their advisors for their project work. The adviser points are not included in the comparison, since the graphs illustrate the points earned for writing quality and use of the design tools, not for the technical merit of the project.

Figure 8 shows the results for the capstone students. The range was much less, with a difference of 12 points between the top and lowest scoring reports. Confidential comments on the peer contribution rating forms turned in by the teams identified three teams that had some conflicts due to members not working hard—these teams turned in the three lowest-scoring reports. The capstone points were normalized from a possible maximum of 125, where 75 additional points maximum were added as supplied by the project advisers. This graph shows a high degree of homogeneity—which we attribute to these teams having been purposefully formed to be balanced in thinking styles. For the course grade, scores above 92 = A, above 82 = B, above 72 = C, and at or below 72 = F (no D grades were given). However, intermediate grades of AB and BC were given. Grades in the two figures below were rounded off to simplify the bar graphs.

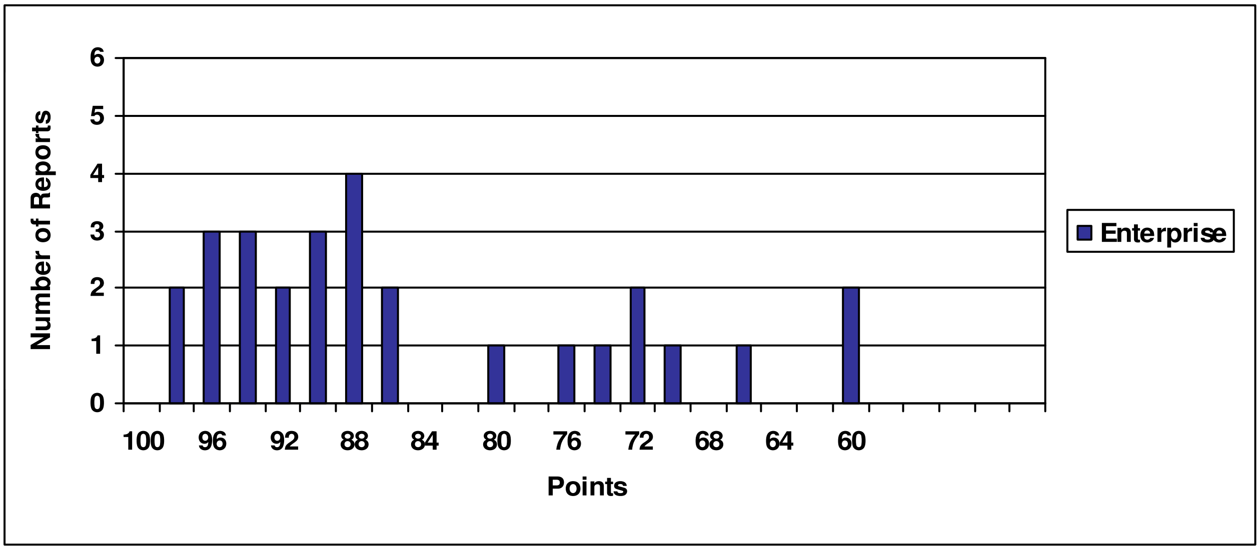

Figure 7 Final Report Grade Distribution for the Enterprise Students (normalized)

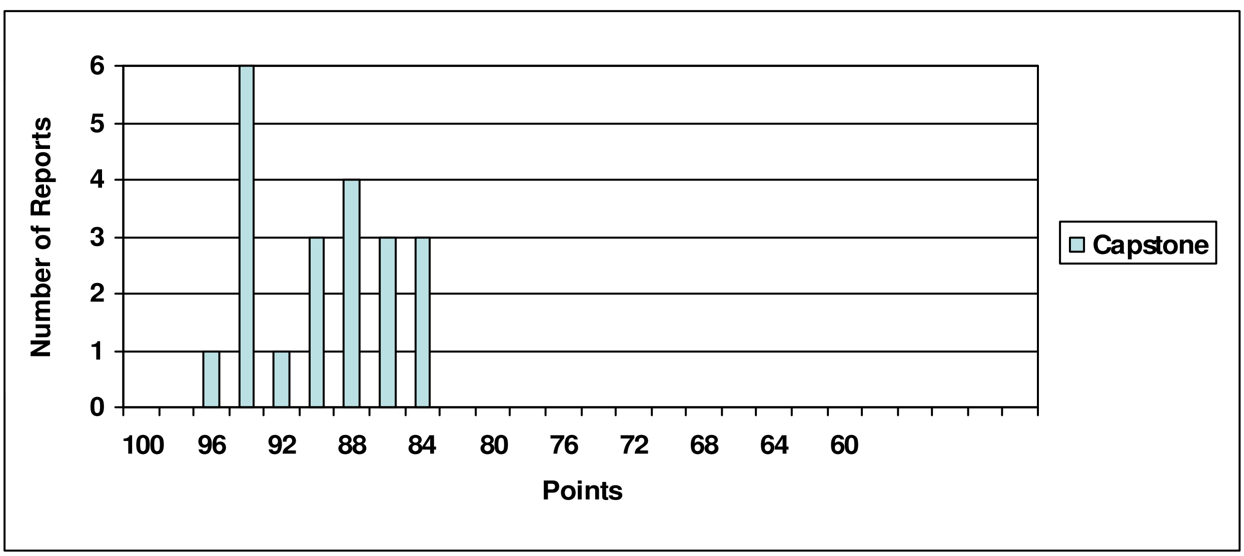

Figure 8 Final Report Grade Distribution for the Capstone Students (normalized)

The lower-ranking reports still contained substantial errors, such as mistakes in the Pugh method, no updating from previous sections, not following the templates or prescribed formats, and again repeating previously made mistakes, including incorrect placement of figure or table captions (and left-facing orientation of wide page-sized charts). Also, capitalization in tables remained inconsistent, even though pointed out for correction in previous reports. Some students continued to omit the cover letter (or did not follow an acceptable business letter format).

Based on the results of Figure 8 when compared to Figure 7, we asked the question: Is there a correlation between a good report grade and the presence of a student with a high score in the thinking style needed for communication and teamwork (quadrant C in the HBDI model)? The average score quadrant C in this class as a whole was 47. The average highest score for the top seven reports was 75, for the next seven reports 73, and for the lowest seven reports 65. Is it a coincidence that the three lowest scores for this thinking style were among the “bottom” group?

A scatter diagram showing correlation between the highest quadrant C thinking preference by an enterprise member of a team or an individual submitting a report is shown in Figure 9. Although the data points are widely scattered, some correlation between stronger quadrant C thinking preference and higher report scores can be seen. The calculated correlation coefficients are 0.38 for capstone and 0.21 for enterprise. As shown by the enterprise results, students with lower quadrant C thinking preferences can still achieve top quality—if they are motivated and make a strong effort—and many resources are provided for them to learn to meet the requirements.

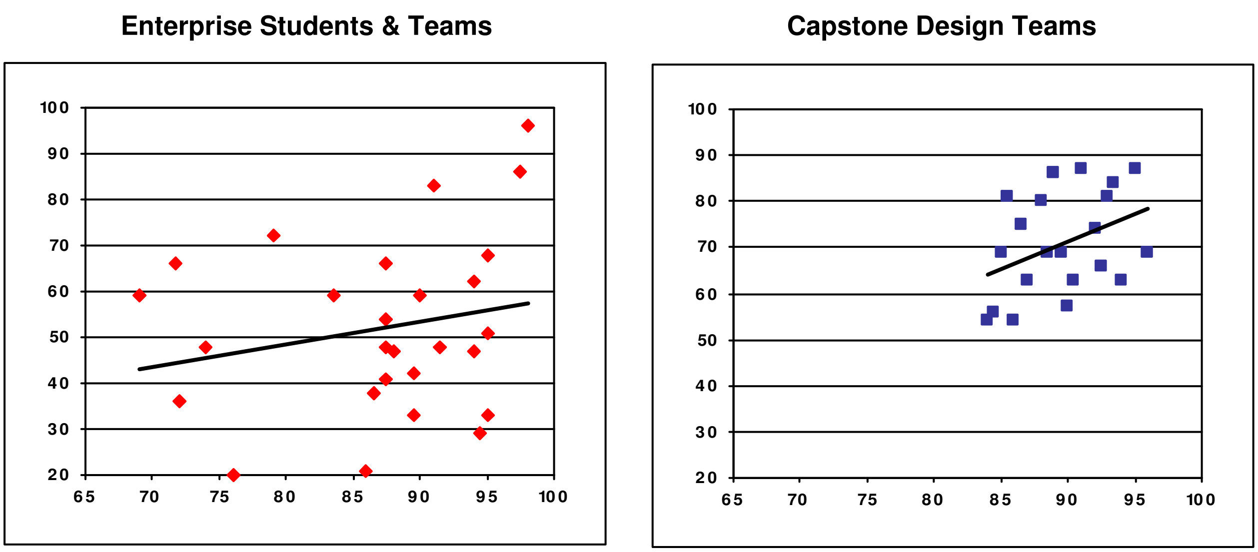

Figure 9   Correlation between “C” Thinking Preference (y-axis) and Report Grade (x-axis)

Team size did not seem to correlate with the final report grades for the enterprise students. One team of three students ranked at the top with 98 points, one at 90, and the third at 71—this was a team where two students complained about the third member not carrying his load. The report grades from teams made up of two students were distributed across a range from 98 to 74. The scatter diagram and Figure 7 show that the enterprise program attracts students of various abilities, some who are top performers and some who are doing poor academic work and chose the enterprise option to escape the more stringent requirements of the capstone design option.

But because the enterprise students took three required credits of instruction in teaming and communications, it was surprising that many of their written reports were so poorly done.

Conclusions and Recommendations

Based on the experiences and results from the fall 2007 capstone design course, the following conclusions can be reached:

1. Forming project teams with a balanced thinking styles composition appears to have some influence on report quality—with the critical factor being the presence of at least one team member having a strong preference for the thinking modes related to communication and teamwork (if possible at least 15 to 20 points higher than the average of 45 to 50 in HBDI quadrant C for typical engineering seniors[5-8]). This fits with Richard M. Felder's findings that to function successfully as an engineer, students must develop skills characteristic of all learning styles.[13] Engineering design faculty members and others in the education field have recognized the advantages of cooperative learning using diverse student teams and are using a variety of instruments for forming balanced teams with similar results[14] (MBTI[15], Kolb[16], Felder-Silverman[13], HBDI[7], Kersey Temperament Sorter II[17]). Although the team dynamics were monitored throughout the semester, and students were aware that a lack of contribution would have consequences on their individual grade, a few still chose to slack off. Sadly, the presence of a non-performing team member had some effect on the quality of the end-of-term team reports.
2. Having a qualified technical writer on the instructional team was crucial—this was a person not only experienced in editing technical reports but also thoroughly familiar with the design process and many tools being taught.
3. Because many stakeholders (especially engineering faculty, committee members, and departmental administrators) were involved in the continuous improvement effort related to the capstone design course, managing the logistics and especially the communications with the project advisors would have gone more smoothly if the graduate assistants had stronger interpersonal skills. The assistants were assigned to the course by the administration.

To improve the technical writing skills as well as the capstone design or enterprise project results, the following actions are recommended:

4. If enterprise students continue to be required to take the first semester of the senior capstone design course, then it is strongly recommended that they submit a project proposal for approval as early as the end of the junior year to the course instructor (or a design committee review panel which includes the course instructor) to assure that the project has solid up-front design content, so the design process and tools taught can be immediately applied for tacit learning. Also, the panel should review the final reports of the enterprise students in the capstone design class and make recommendations for remedial work to be completed before these students are allowed to graduate.
5. Capstone design is resource intensive[18], and for class sizes exceeding ten teams, a team of two mechanical engineering instructors is recommended for optimum results (in addition to a technical writer, a doctoral teaching assistant, and other administrative support).
6. Just-in-time teaching of the design tools appears to be very important, but other skills, such as creativity and technical communication (verbal, written, and visual/graphical) should be acquired or honed starting with the freshman year, as summarized in Table 3.

Table 3 Objectives, Criteria, and Scheduling for an Optimal Capstone Design Outcome

Why	What	When		
Objectives	**Criteria**	**Years 1 & 2**	**Year 3**	**Year 4**
Meet ABET Criteria Succeed in a Globally Competitive World Learn the Conceptual Design Process Meet Project Sponsor Requirements	1. Development of student creativity			
	2. Use of open-ended problems			
	3. Alternate design solutions and decision rationale (Pugh method)			
	4. Use of modern design theory and methodologies			
	5. Formulation of design statements and specifications			
	6. Feasibility considerations			
	7. Consideration of production processes			
	8. Concurrent engineering design			
	9. Detailed system description			
	10. Use of teams in problem solving and design work; development of leadership			
	11. Realistic constraints (including DFX, economic factors, etc.)			
	12. Development of related communication skills			
	13. Production of required documentation			
	14. Ability to do whole-brain thinking			
	15. Ability to apply the creative problem solving process to a conceptual design problem			
	16. Ability to apply engineering analysis in complex open-ended problems			
	17. Use of quality tools (QFD, FMEA, robust engineering, etc.)			
	18. Engineering ethics, intellectual property, other just-in-time topics depending on project needs			
	19. Achieve an excellent project outcome			

Engineering students need practice on how to apply engineering analysis to open-ended problems before reaching the senior year.[19] The recommendations for Year 3 for the capstone design sequence should ideally be offered to students in the enterprise program starting with Year 2, if the quality of many of their enterprises (and their learning) is to reach a more uniform level comparable to the capstone design track. According to Florida Tech, having a foundational mechanical engineering cornerstone design experience in the first year *"greatly facilitates the integration of meaningful design experiences across the curriculum in that it produces sophomore-year students that have the basic skills and experiences necessary to manage and execute design project teams. These skills are easily drawn upon in other engineering courses with minimal effort required of the faculty."*[17]

7. Advisors have a crucial role in guiding the students and evaluating the technical merit of their projects, both in capstone design and in enterprise, requiring a considerable investment in time. Thus they should not only be rewarded accordingly, but also receive some training and guidelines, so they will have a common understanding of the conceptual design process and how the students' work is to be evaluated.
8. To counteract low student expectations about the capstone course requirements, attendance at a two-hour briefing session at the end of the preceding spring term should be mandatory for juniors who had signed up for capstone design, so they may be motivated to hone some of their writing skills over their summer break and will have a more realistic idea of the commitment the capstone course will demand of them (as well as the benefits they will gain).
9. Having a detailed software template for writing the three reports might help to get submissions with somewhat higher quality in the specified formats and thus might make that aspect of grading easier, as long as it has some flexibility that allows the more creative teams to introduce style changes to personalize their reports.

Remaining Challenges

How can instructors get students to pay attention, read assigned material, follow directions and procedures, and think critically? Why do college students seem to increasingly lack these abilities? Engineering educators need to watch for research done on the influence of television watching and video gaming on the brain starting from an early age, how this affects how students learn, and how teaching methods may need to be changed for more effective learning in the engineering curriculum. *"Better writing requires better thinking which generates deeper understanding"* [20] and consequently will yield better project results and optimal learning.

Research has shown that the percent distribution of first-year engineering students with right-brain thinking preferences is double that of senior classes.[8] The traditional engineering curriculum and learning environment is hostile to these students—many of them opt out of engineering, even when they have a high grade point average.[21-23] Teaching to all four thinking/learning styles (irrespective of the model used) has a direct positive effect on student retention, especially for those with preferences for quadrant C thinking.[8,14] We have found that introducing creative problem solving and design at the freshman level has a beneficial influence on retention of students with right-brain thinking preferences.[8] Industry is seeking engineering graduates with good communication, leadership and teamwork skills (and can think innovatively) to remain competitive in today's global marketplace. In the global arena, good communication skills for engineers and engineering students have key advantages[24]:

- Good communication skills (oral and written) are crucial for strategic advantage in international business and industry.
- They improve the profile of the professional engineer and aid in recruiting students.
- Group projects and presentations develop essential interpersonal and negotiation skills.
- Interpersonal skills enhance leadership and advancement on a successful career path.

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