AC 2010-226: A HOLISTIC APPROACH FOR STUDENT ASSESSMENT IN PROJECT-BASED MULTIDISCIPLINARY ENGINEERING CAPSTONE DESIGN

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Abstract

A capstone design course involves multiple variables and complexities which make its teaching conspicuously challenging[1,2]; e.g., sponsors' requirements, team dynamics, and available resources, as well as the usual engineering educational goals. At the core of the challenge is assessment – giving each student a fair final grade. In this paper we describe a holistic approach to developing a fair and accurate evaluation of individual students in multidisciplinary teams. The rubrics of the approach include faculty assessment of communication skills, team participation, design process, and project results, with input from students and sponsors to calibrate the evaluations of the instructors. This approach represents an evolution from our traditional methods, which were based primarily on group reports, and student peer evaluations. In addition, we adopted a new team teaching approach that facilitates multidisciplinary participation; and also made the grading processes more objective by separating the roles associated with instructor, coaching, and judging. Furthermore, implementation of a communication intensive requirement provided greater insight into individual student contributions. The holistic approach allows greater consistency in the grading process yet is flexible enough to handle a wide variety of multidisciplinary design projects and helps accommodate different disciplinary foci. We submit that the basic structure of the assessment (i.e., blending objectives with procedural justice and evaluation from multiple sources) is consistent with practices in industry that students will face after their graduation.

Background and Outline of Paper

Experienced engineers commonly agree that most of the design problems they face in practice are multi-faceted challenges that involve conflicting trade-offs and ambiguities that are solved via an iterative process. In support of this reality, ABET calls for a capstone design experience prior to graduation that teaches engineering students about teamwork, communication, and the engineering design process.[3] In a university environment where faculty members specialize in disciplinary areas, teaching a multidisciplinary capstone design course where a diversity of knowledge, skills, and experience is required can be a challenging situation. Our experience is that engineering instructors are sometimes uncomfortable teaching a capstone course because of the uncertainties associated with providing fair and accurate assessment of individual student performance.

This paper is based on our work over the past ten years.[4] It begins with a brief discussion of some of the factors that influence capstone projects, an overview of the characteristics of our program and then a process timeline for our capstone design course. The following section focuses on three changes that were made in 2008-09 to improve understanding of student assessment, namely; project level administration, separation of mentoring and assessment roles, and grading rubrics for engineering communication assignments. The concluding section discusses the consistency of assessment inputs in our current approach and summarizes lessons learned.

Factors Influencing Capstone Design Courses

Multidisciplinary capstone design projects represent an integrative opportunity in a student's educational journey as they transition from engineering education to practice. While capstone design courses can (and should) be challenging for students, assessment in the context of design projects for instructors is especially challenging. This is due in part to the multiple learning objectives involved which broadly include teamwork, communication and the design process. Figure 1 identifies many of the factors that have the opportunity to influence capstone design projects.

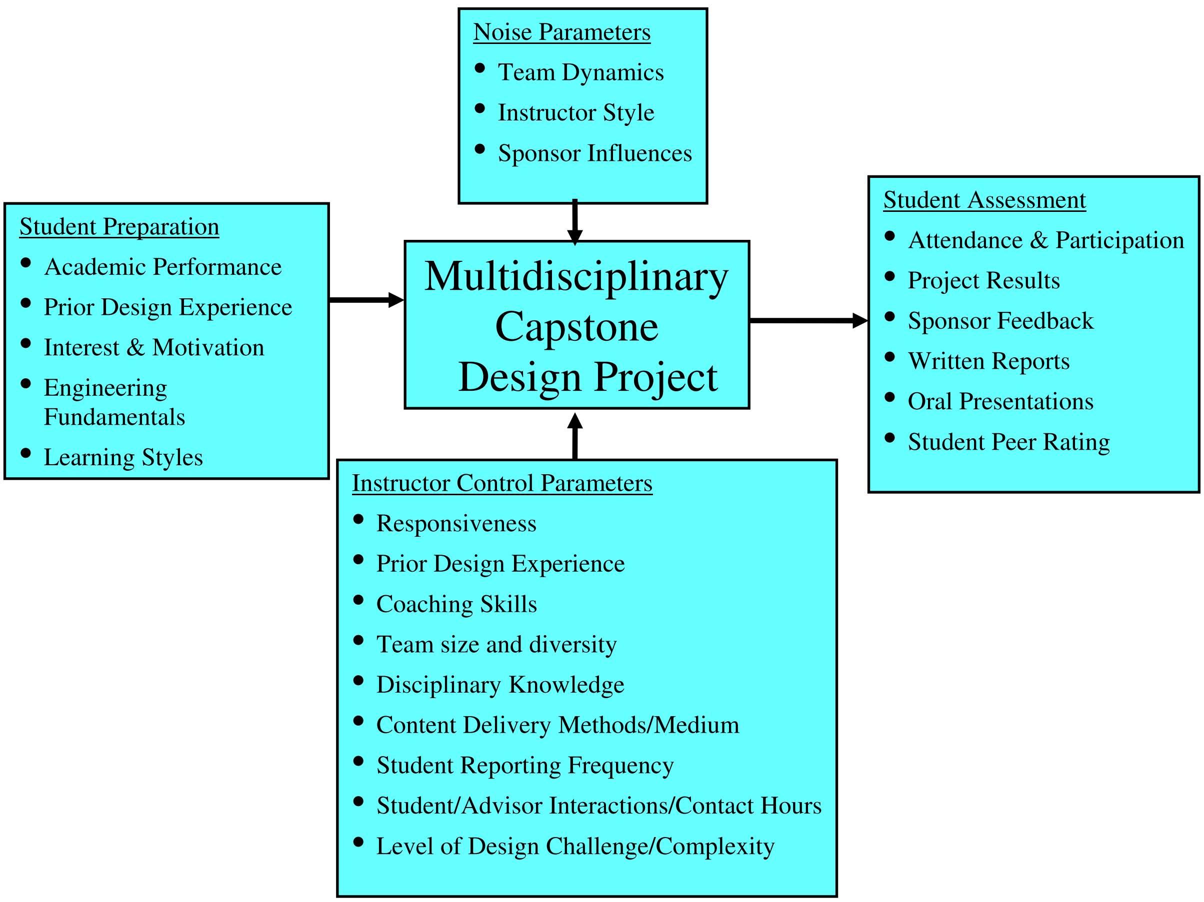

Figure 1 – Factors that influence multidisciplinary capstone design project outcomes

To organize the paper, we have identified three levels of control for the factors that influence capstone design courses.

Course Level Administration

Based upon our experience with capstone design courses, we have found that, given the many potentially interacting factors, it is essential that a foundational set of processes and milestones are in place to guide the student experience and monitor progress. At the course level it is important to have policies, procedures, and guidelines in place for such matters as safety, purchasing, and meeting practices. Pre-project preparation includes scoping of project parameters, identification of technology study areas, and student team formation. While predefined processes are important, it is also true that both instructors and students need to be flexible and able to appropriately respond to changing situations. Support systems must be in place that can respond on-demand to individual project needs.

Project Level Grading

While most academic institutions operate at a course section level, for capstone design we argue that course administration should be at a project level. In this way, project-level reporting on factors such as teamwork, progress on relevant objectives, project challenge level, resource requirements, and sponsor interaction can be monitored on a regular basis. Project level reporting of team grades facilitates consistency of delivery across the entire course. We have noticed that a dichotomy also exists in terms of the roles that instructors must play while advising project teams. In one case instructors will act as “coach” and “mentor” in support of the team, but in another case they need to monitor progress and ultimately assign a grade. These conflicting roles can have an emotional impact on the instructor, when the same person who is at one point supporting team success must now change roles and act like a “referee” or “judge” to make assessment.

Individual Student Level Assessment

A major challenge for instructors is the difficulty involved with making individual assessments when students are working together as members of a team in the context of a capstone course. Even when the overall team grade for the project is clear, it can be difficult to discern the contributions and participation of one team member compared to the other members of a team. Use of student peer evaluations is very helpful in this regard. Another dimension for assessing individual student contribution and participation occurs through communication intensive requirements, which in our case accounts for 25% of the individual student final grade. Student posting to an on-line project management website[5] is part of this requirement and provides a useful calibration point for individual contributions.

Characteristics of the Program

The program includes the following characteristics:

- The program is situated at a private research university.
- All projects are approached in an authentic “clinical” real world fashion.

- A single semester multidisciplinary capstone involving electrical, mechanical, computer systems and industrial engineering students with a common syllabus across all participating departments.
- A small percentage (less than 5%) of aerospace, biomedical, and materials engineering students also participate and also follow the common syllabus.
- Projects come from a combination of industry, service, or entrepreneurial sources with over 60% of projects from industry sources, each funded by an annual grant of $40K.
- Average team size: 7 to 8 students
- Number of project teams each semester: 25

The Overall Design of the Evaluation Framework

Philosophically, as well as in practice, the final grade is determined by two basic factors: the grade for the project and the adjustment for individuals. The grade for the project is assigned by the project's instructional team, based on the sponsor's input (including the written evaluations of the project's output and the team's presentations to the sponsor); the team's group deliverables (including statement of work, midterm report, and final report); and the instructors' evaluation of the team's design process according to engineering science. The third element, i.e., the instructors' evaluation, is typically reserved as a calibration tool to account for the variances in difficulty that each project faces. Therefore, in a typical project, the project grade is sufficiently determined by the sponsor's input and the team's group deliverables. The instructors may use their discretion to adjust the grade for some extreme cases (e.g., unusual events), including facilitating the team to undertake additional tasks, and dealing with cases where it is difficult to get the attention of sponsor representatives when critical guidance is needed.

The individual grade for each student is, in essence, an individual adjustment from the project grade in accordance with the student's individual deliverables (including technical memos, participation in the project forum, and self assessment), peer reviews, and the instructors' evaluation of their individual performances and contributions. While self assessment, peer reviews, and instructor reviews are all subjective, the collection of them provides a mosaic of the student that is as objective as any traditional metric can be. Coupled with the written records in the form of individual deliverables, these reviews substantiate an appropriate adjustment to the final grade for a student.

The instructor team, consisting of the mentor and the evaluator, works with the students throughout the project in an advisor, rather than teacher, function. By division of labor, the mentor is supposed to work more closely with the students on the problem, while the evaluator on the process and deliverables. However, this division is fluid depending on the expertise of the instructors and the needs of the team at the time. In general the evaluator consults with the mentor to decide the final grades for the project and each student and a consensus is essentially always reached. We attribute the fact that this consensus exists in our practices to the inherent fairness of the holistic grading process: it naturally reveals and leads to a logical assessment of the students' performances.

Major Course Milestones, Assignments, and Grading

Since 2001 we have iteratively refined our syllabus, course assignments, and support processes that are common to all students and participating departments. Figure 2 shows the structure of the course.

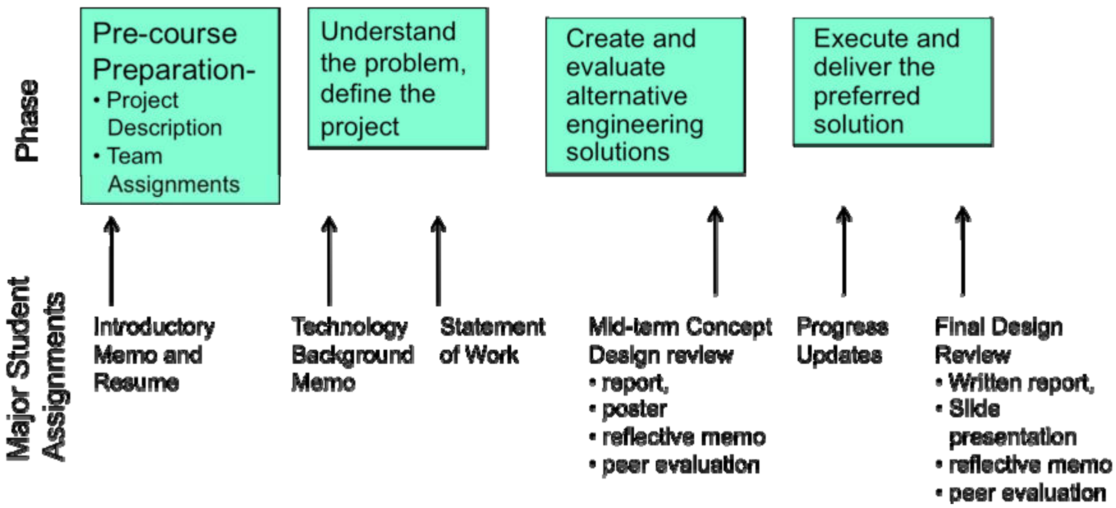

Figure 2 – Course structure and major student assignments

The syllabus includes the following major course milestones and assignments:

Pre-course Assignment - Introductory Memo and resume: This assignment is submitted by each student in the semester prior to project team formation. The information provided by students is used to understand their interests and capability and ultimately to match them to appropriate projects.

Project team formation: Just prior to the first week of classes students are informed of their project assignment. On the first day of class, students are engaged in a variety of introductory team forming (i.e., building) activities.

Technology Background Memo: After classes begin the first assignment for each student is to conduct background research in an area of interest related to the project. This assignment is an individual writing assignment due during the second week of classes.

Statement of Work: This assignment is the first significant team milestone where students are expected to clearly and concisely communicate the project objectives, plans, and deliverables for the semester.

Mid-term Concept Design Review: At this major milestone student teams are expected to have fully defined the problem and identified viable solution paths. This design review is conducted as a poster session that includes a combination of student, instructor and external reviewer feedback and assessment.

Progress Updates: After the mid-term design review and until the end of the semester each student team works to implement their project plan and ultimately demonstrate results. During this time instructor and sponsor mentors support team efforts, while evaluators observe and monitor progress through postings on the project forum, conference calls with customers and impromptu project updates by individual students.

Final Design Review: The final semester design review is an intensive one to two hour session where a student team makes a comprehensive presentation and is expected to demonstrate their expert knowledge of the project before a panel of judges.

Three quarters of an individual student's final grade is based upon their contributions to the team project. A team project grade is first developed for the major project milestones to which a contribution factor is applied to arrive at each individual student grade. The remaining 25% of a student's grade is based upon individual communication assignments that occur throughout the semester. Major project milestone grades are based upon progress on relevant objectives that include teamwork, design methodology and project management.

ANALYSIS OF CHANGES MADE BEGINNING WITH THE 2008-09 ACADEMIC YEAR

During the 2008 and 2009 academic year we introduced the following changes into the existing program:

- Implemented Project Level Course Organization: Instead of organizing the course at a 'section" level we chose to do so by project team. This included course and instructor evaluations. This way we would be able to discern and compare consistency of team grades with team performance at a higher resolution (i.e., at the project team level versus course level) and potentially account for why one team may have performed differently from another.

- Introduced Roles of Project Engineer and Chief Engineer: We assigned two instructors per project team. One instructor as project engineer would primarily take on the role of mentor and coach. The other instructor as chief engineer would primarily take on the role of evaluator and be responsible for assessing team performance and assigning a final grade for each student.

- Implemented Communication Intensive Requirements: We implemented an Institute level "communication intensive requirement" in to the Design Lab capstone course syllabus that called for each student to compose, at a minimum, the equivalent of 15 pages of writing and for instructors (i.e., the chief engineer) to conduct individual student assessments.

In Fall 2008 and Spring 2009 we conducted course surveys at a project level as measured by the IDEA Diagnostic Form Report[8]. We obtained results for 15 teams in Fall 2008 and 20 teams in Spring 2009 where the average IDEA Survey response rate was 70% for a total of 168 students reporting across both semesters. As discussed next, we have used these survey data together with information from student reflective memos, to gain insights into the effects of the three course changes.

Project Level Course Organization

Conducting course evaluations at a project team level has provided additional insight on the importance of teamwork as a learning objective for multidisciplinary capstone design.[9] Depending upon the personalities of various team members, we have found that teamwork can easily become confounded under various situations, such as, 1) No one emerges as a leader, 2) Students sit back and wait for instructor to lead, and 3) Difficult personality on the team. Using a combination of regular bi-weekly interactions during scheduled team meetings, student peer evaluations and monitoring postings in an on-line collaboration tool, we have learned over time to be very attentive to teamwork issues, especially during the first few weeks of the semester.

Using questions adapted from NSF sponsored research in assessing capstone design[2] students prepared peer evaluations at both the mid-term and the end of the semester. Concurrently with peer evaluations, each student was also asked to write a reflective memo. Both the reflective memo and peer evaluation questions were designed to force the student to think critically about their team experience. The words used for the assignment are shown in figure 3 below.

For this assignment you should reflect upon your participation on the project and comment on your key strengths and how it has contributed to the overall effort. You should also describe possible weaknesses and opportunities for improvement, the major challenges and issues faced, and what you have learned from the experience. Comment on what might have been done differently to make your learning experience more productive.

In addition, you should prepare a peer evaluation for everyone on your team. List the names of each member of your team, including yourself. For each team member you should describe their performance and contribution to the overall team effort. For each team member identify a key strength, identify an area for improvement for each team member, and suggest how this might be achieved. Finally, if you were in a position of assigning a grade to each individual on the team based upon what you have observed to date, what would the grade be? Please use the following grading system: A=4, A-=3.67, B+=3.33, B=3, B-=2.67, C+=2.33, C=2, C-=1.67, D+=1.33, D=1, F=0.

Questions that you should consider for each team member include:

1. Did they attend meetings, follow through on their commitments, and meet deadlines?
2. Were they open to the ideas of others and treat others with respect?
3. Did they share ideas and make a fair contribution to the team effort?
4. Did they have a positive attitude and conduct themselves in a professional manner?
5. Did they support the goals of the team and stay focused on project objectives?

Figure 3 - Reflective Memo and Peer Evaluation Assignment

The mid-term evaluations were used to assess whether any team issues exist among students. At the end of each semester when students were asked to reflect upon their project experience, we found strong correlations (.78) between instructor project milestone assessments and average team peer evaluations for 20 projects across Fall and Spring semesters in which we were able to collect representative data (see table 1). Students on average graded themselves higher by less than a half letter grade from the instructor project milestone team grade. Data from past years indicates similar correlations between team milestone grades, external design review ratings, and final semester student peer evaluations.

Table 1 – Milestone Grades versus Peer Evaluations for 20 Project Teams

Project Team	Milestone Grade	Peer Evaluations
SHA – Fall 2008	3.30	3.70
SK – Fall 2008	3.48	3.47
KI – Fall 2008	3.58	3.80
SD – Fall 2008	3.12	3.34
PS – Fall 2008	2.73	2.93
SS – Spring 2009	3.48	3.45
SK – Spring 2009	3.78	3.71
SM – Spring 2009	2.32	2.78
BA – Spring 2009	3.25	3.44
WTI – Spring 2009	3.33	3.40
FTU – Spring 2009	3.66	3.80
PMA – Spring 2009	3.66	3.40
HL – Spring 2009	3.00	3.30
PFC – Spring 2009	3.30	3.40
WTI – Fall 2008	3.30	3.70
FTU – Fall 2008	3.66	3.40
HL – Fall 2008	3.00	3.20
PIP – Fall 2008	3.30	3.60
SS – Fall 2008	3.30	3.70
SA – Fall 2008	3.60	3.40

In the cases where student teams differed by greater than a half letter grade from their final milestone team grade, there was always a mitigating factor that inhibited teamwork. While team size is sometimes raised as a mitigating factor, we found that there was little significant correlation (-.1) between course ratings (on a 1 to 5 scale) and team size, which ranged from 5 to 9 students per team, which is consistent with prior work.[6] A relatively large positive correlation (of .565) existed between course ratings and how much students felt they learned about teamwork. The implication here is if instructors emphasize teamwork (regardless of team size) and support students in this regard, this should enhance student team performance and the opportunity for them to be successful.

The Roles of Project and Chief Engineer

Having multiple "faculty advisors" in a team teaching environment could be confusing to students and potentially present a conflict of views between the advisors. However, our experience over the past year has been that this actually rarely occurred. We believe that this was facilitated in part by clearly defining the roles and responsibilities of the "chief engineer" and "project engineer". However, a more fundamental reason that we would like to attribute the success to is the spirit shared by both the faculty and the students that they would make necessary adjustments to achieve the project goals, including both educational and sponsors' objectives.

The student's team spirit of project success generally set the tone for all grades. This single, common measure helped the faculty advisors cultivate their team spirit and promote their teamwork. Sidebar discussion was a technique commonly used by the faculty to bring individual students on board if they were being observed as lacking in their performance and/or teamwork. However, peer pressure was proven to be really effective in this regard. The faculty often only needed to steer and smooth out rough edges when they appeared, rather than having to carry the whole team on their shoulders.

A major benefit of the team teaching approach becomes the opportunity to have multiple perspectives and a larger experience base to share with students and to collect assessment data. The introduction of the evaluator role facilitated our ability to implement our communication intensive requirement thus permitting focused assessment on individual students. There were no students who commented about the team teaching arrangement in the end of the semester course survey and few students contesting their final grades.

Communication Intensive Requirements and Grading Rubrics

The communication intensive requirement was implemented broadly across the university in the interest of ensuring that students be able to communicate effectively in a variety of media (written, spoken, visual, electronic) and in a variety of genres (reports, proposals, etc.).[7] Whatever the medium and genre, the communication intensive requirement insisted that students should be able to:

1. **Understand the context in which they are communicating,**

   a. Identifying the goals of and audience for their communication
   b. Using their understanding of goals and audience to choose appropriate media, language, and content

2. **Organize their work,**

   a. Establishing a clear structure or principle of organization
   b. Creating effective introductory and concluding passages in which they identify their main point and set their work in a larger context

3. **Develop content appropriately,**

   a. Displaying a clear ethical sensibility (e.g., reporting data accurately, citing sources of information)
   b. Asserting and elaborating on claims using evidence and reasoning that are appropriate for their audience and their discipline/profession
   c. Addressing the questions and/or topics that are essential for success with a given assignment
   d. Understanding, and, as appropriate, applying principles of visual communication (graphs, charts, animations, pictures) in their written or spoken work

4. **Edit their written work carefully,**

a. Observing the conventions of Standard English (e.g., correct usage, sentence structure, spelling, and punctuation)
b. Observing the conventions (e.g., terminology and page format) of a particular discipline or workplace

From these general requirements we created grading rubrics for each specific individual assignment that reflected the intent and satisfied the objectives of the communication intensive requirement. Table 1 shows an example of such a rubric for the technology background memo.

Table 1. Grading rubric for the technology background memo.

	Excellent	**Good**	**Fair**	**Poor**
Structure, Style and Editing (C1, C2,C4, C9 &C10)	The work is well structured, including introduction and conclusion sections, with appropriate style and is free of errors in language. (2.0)	The structure and style are appropriate with few errors in language. (1.5)	The work includes all elements of a memo but contains distracting style and editing problems. (1.0)	The work is not written in an appropriate memo format and contains numerous style and editing problems. (0.0)
Useful information content (C7)	Contains much useful information critical for moving forward with the project. (4)	The memo is thorough and contains useful information. (3)	The memo contains some useful information (2)	The memo is not useful and/or too brief. (1)
Organization and logic (C3, C6, C8)	Information is well organized with insights and implications for project decisions clearly defined. Appropriate visual elements, such as Tables and Figures, are used. (2.5)	Information and implications are there, but require some effort to discern the implications for the project. Appropriate visual elements, such as Tables and Figures, are used. (1.5)	Information and implications misinterpreted or very difficult to discern (0 .5)	Poor organization of information; project implications unclear (0.0)

References and Citations (C5)	All information is cited in text, and the sources are correctly documented so that follow-up to the original sources is straightforward. (1.5)	All information is cited in text, and some information sources, such as information obtained from the Internet, are not correctly documented. (1.0)	Some information sources are not documented. (0.5)	No information source is presented. (0.0)

Overall results from implementation of the communication intensive requirement were greater insight into individual student performance. The grading rubric facilitated clear feedback to students and grading productivity for instructors.

Summary Observations and Conclusions

As a "holistic" approach suggests, our assessment methodology employs a broad spectrum of inputs from a variety of sources. Collectively these inputs provide confidence in our final grades with regard to student understanding, application of appropriate use of the design process, teamwork, communication, and overall contribution to project success. Overall we have found that project level course administration has introduced greater resolution and insight into understanding and improving student assessment and that separating mentor and evaluator roles is effective in maintaining clarity in technical advice and in performance expectations in the context of multidisciplinary capstone design project-based learning.

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