Capstone Design Assessment and Student Motivation

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Abstract— **This paper presents the ongoing development of student assessment strategies, and how they affect student motivation and satisfaction, in a mechanical engineering capstone course sequence. The capstone sequence discussed contains large scale projects consisting of ten to twenty students broken into smaller subgroups with specific tasks. Because the capstone sequence is a requirement for all mechanical engineering students, the projects and subgroups include students with varying degrees of ability, motivation and dedication. These differences often cause tension as the projects develop, especially during the build phase. The first step in addressing this issue was to conduct milestone evaluations holding individual team members responsible to the group for their progress. The milestone evaluations included strict penalties to insure students did not interfere with the progress of other students. To further address this problem, a milestone point system was developed to ensure that proper credit was given for each student's contribution to the completion of the milestone. The new milestone evaluations were used in conjunction with individual assessment of oral presentations, engineering notebooks, and written reports. The proposed future development of the assessment system includes incorporating weekly five minute oral updates from each student along with the weekly notebook evaluation. Additionally, it is proposed that alumni who have completed the same project be included in the assessment process.**

***Index Terms*—Capstone, Senior Design, Assessment**

I. Introduction

FROM its inception, the York College Mechanical Engineering Program has always prided itself on being a "hands-on" engineering program. Lab experiences are used heavily throughout the academic curriculum to reinforce lecture material, and all students are required to complete three separate terms of co-op experience as a graduation requirement (Mechanical Engineering Program Curriculum, York College of Pennsylvania, http://cagtalog.ycp.edu[1]). The capstone design sequence follows this "hands-on" approach and contains two semesters of design, build, and test phases. Whereas the students gain experience working on small project designs during their co-op semesters, the capstone course contains a large scale project where the students are divided into subgroups that work together to complete the entire project. The projects typically contain 10-20 students broken into subgroups of 3-4 students. An example of this type of project is the design and build of a car to complete in the Society of Automotive Engineers Formula Collegiate Design Competition (FSAE)[2].

While there is some overlap, the first semester of the capstone sequence focuses on the design aspects of the project, and the second semester of the project focuses on the build and testing of the prototype. The goal is to have a complete CAD model with all necessary analysis completed by the end of the first semester, and have a functional prototype by the end of the second semester.

The capstone course sequence is required for all students in the Mechanical Engineering Program. Consequently, the projects include students with a broad range of experience, academic ability, and motivation. Typically there are three or four different projects offered per semester, and the students are allowed to request which project and subgroup they would like to work with. There are usually two course instructors that oversee all of the capstone projects. Students are assessed on their performance in presentations, weekly notebook entries, milestone contribution, professionalism, and a final technical report. How much influence each measurement has on final course grades is dependent on whether the students are in the design semester or the build semester, but they are roughly equal parts. This paper focuses on changes to assessment measures over the past four years, focusing on recent changes in the milestone system.

II. Historical Assessment Methods

For the past several years, assessment methods have continued to evolve each time the capstone course sequence is taught. The primary goals of any changes to the assessment measures have been to (1) increase individual student accountability to the project, (2) specifically encourage students who aren't "pulling their weight" to increase their productivity, and (3) ensure that the projects are completed with sufficient time for vehicle testing prior to competition dates.

A. Previous Assessment System

Four years ago, the capstone course sequence included four main assessment activities: engineering notebooks, formal reports, design presentations, and professionalism. The engineering notebooks were reviewed and graded for each individual student once every week. Feedback was given to

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the students in their design notebook along with their assigned grade. Each student was also required to individually produce one written report at the midpoint of each semester, and a final report at the end of each semester. As a subgroup, students gave a design presentation at the midpoint of the semester, and produced a poster presentation for the end of each semester. In addition, there was a presentation of the final design by the entire group at the end of each semester. Professionalism grades were calculated based on peer evaluation and instructor observation. As the design semester progressed, students developed their own timelines for the organization of the build semester.

B. Feedback from Students

The capstone projects push students to their limits, and standards need to be set very high for student performance if the projects are to be completed well. As a result, many students express dissatisfaction with the capstone course in their course evaluations. Much of the dissatisfaction expressed by good students comes from weaker students "just scraping by" without putting in the effort required to have a high quality project design and build. This is why the assessment system has been constantly evolving to try to improve the process to ensure high quality projects and increase student satisfaction with the design projects.

III. Addition of Individual Presentations and Project Milestones

The first two changes that came in the assessment process were (1) the addition of individual research and design presentations to the design semester, and (2) graded milestone dates (to the build semester only in the first year of implementation, then ultimately to both design and build semesters).

A. Individual Design Presentations

In an effort to make students more individually accountable to the group, the midpoint written report was replaced with two individual oral presentations. The first oral presentation was a research presentation that would be done for the entire project team and would occur approximately two weeks into the design phase. At this point, each student was to educate the project team about what their specific activities would be, how they fit into the goals of their subgroup, and how they were important to the complete design. The team was then allowed to ask questions of each student, and each student was evaluated by the course instructors.

The second oral presentation was a midterm design review. Again, each student presented to the entire project group and received feedback from their teammates and the course instructors. This time, they presented design alternatives, preliminary analysis, and their final concept recommendations. One primary objective of the second presentation, from an instructor perspective, was to do a better job with system integration by including all subgroups in the decision making process and for each subgroup to better understand how their designs connect to the final product.

B. Graded Milestones

Several project milestones, with task completion dates, were given to each project subgroup at the beginning of each semester. As a general example, one milestone for the FSAE frame subgroup in the design semester was Seatbelt harness mounts designed/analyzed and modeled in Solidworks. The students were allowed to decide who among them would focus on each individual milestone at the beginning of the course. The instructors would redistribute tasks as necessary to maintain consistency in workload, but this was typically not necessary.

Figure 1 shows the assessment rubric that was used to evaluate each individual milestone. A high weighting factor was assigned to "Degree of Completion" to encourage the team to stay on track and not let the project fall behind schedule. This milestone system added structure to the project and increased timeliness, but the instructors were confronted with an unanticipated side effect. If a milestone was completed poorly, and the student(s) received an appropriately low grade, there was no motivation to fix the problematic issues. Later, another student would need to put in extra work to compensate for the first weak performance. A corrective action was necessary to hold the original student responsible for completing the task without letting the team fall behind.

In the year following the first introduction of milestones, grades were not assigned for the milestone until the students had completed the milestone to the point where it would not interfere with any other student's work. If a milestone was not complete, it was not given a grade on the due date. Instead, the student(s) responsible were required to continue the task through to a satisfactory degree of completion. A harsh late penalty was also introduced for every day a milestone was incomplete past its deadline. In this way, students were both held responsible for their designated work and encouraged to complete the task in a timely manner.

Table 1 shows the effect of introducing milestones on the timely completion of the projects. The amount of time between vehicle completion and project competition increased with the introduction of milestones and again with the late penalty system. This gave project teams some much-needed time for testing and debugging that was not available in years before the milestone system was implemented.

Topic (Weight)	Unacceptable (0)	Marginal (7)	Exceptional (10)	Points	Weighted Points
Analysis **Weight: 10%**	None completed	Not completed, but correct and useful **or** Complete with minor errors	Everything completed and correct		
Future Plan **Weight: 20%**	None Provided	Not thorough **and/or** Not reasonable **and/or** Unclear deadlines	Thorough and reasonable including deadlines for all necessary tasks		
Degree of Completion **Weight: 50%**	Project may be started, but no part carried to completion	Very minor finishing work needed	Complete		
Confidence **Weight: 20%**	No confidence in analysis, quality of manufacture, and possibility of meeting future plan	Questionable analysis **and/or** Questionable quality of manfacture **and/or** Unrealistic possibility of meeting future plan	Nothing questionable in analysis, high quality craftsmanship, and clear ability to meet future plan deadlines		
TOTAL					

FIGURE 1: MILESTONE ASSESSMENT RUBRIC

TABLE 1: AVAILABLE TIME FOR VEHICLE TESTING BETWEEN DRIVABLE CAR AND PROJECT COMPETITION

	2011	2012 (introduction of milestones)	2013 (introduction of late penalties)	2014
Formula SAE	**0 days**	**1 day**	**21 days**	**40 days**
Baja SAE	**Project not done**	**Project not done**	**Project not done**	**60 days**

IV. ADDITION OF A MILESTONE POINT SYSTEM

The milestone system helped ensure that the vehicles were completed on schedule, but initially they did not guarantee a reasonable distribution of work among the students because different tasks required various levels of effort. For instance, two different students may be responsible for two different milestones, one easy and one difficult. The original implementation of milestones did not have a sufficient correction factor for this occasion. In fact, it was not uncommon for some students to put a lot of effort into difficult tasks and receive modest grades while others chose easy milestones and received higher scores. It became clear that the system would benefit from some form of weighting factor to give credit proportional to the difficulty of, and time required by, each milestone.

A point system was devised to weight the contribution of each milestone, and ultimately the overall contribution of each student to the project. A student's total milestone grade for the course would be determined by the weighted average of each milestone to which that person contributed, according to the number of points earned on each milestone. Additionally, the points for a milestone could be split among the students who participated on that task according to their contributions. Finally, if a student earned more than a "satisfactory" amount of points, that person's overall milestone grade would increase. Overall milestone grades are lowered for students who earn fewer points.

Calculating the overall milestone grades is relatively straightforward. Students demonstrated a "satisfactory" amount of work throughout the course by earning 10 milestone points. (This can be any number.) Therefore, the instructors assigned points to each milestone according to workload and ensured that the total number of all milestone points for the entire project was 10 times the number of students. Therefore, if all students contribute equally and the project is complete, then they all earn a satisfactory number of points and their milestone grade is the weighted average of their individual milestone contributions. If some students do more/less work, then the points redistribute credit and the students will earn appropriate credit. Table 2 shows two example calculations for overall student milestone grades based on individual milestone points and grades. In each case, the hypothetical student contributed to three milestones. Note that in the first case only 8 milestone points were earned, so the overall milestone grade is lowered. If a student earns 10 total points, then the milestone with the most points earned will contribute the most to the overall grade.

TABLE 2: TWO HYPOTHETICAL CALCULATIONS TO DETERMINE A STUDENT'S OVERALL MILESTONE GRADE

Milestone	Milestone Grade (from grading rubric)	Points Earned (distributed among all students who worked on milestone)	Milestone Credit
Frame Fabrication (14 points possible)	95	4	38 $\left(\frac{4}{10} \times 95\right)$
Seatbelt Harness (4 points possible)	75	2	15 $\left(\frac{2}{10} \times 75\right)$
Electrical Enclosure (4 points possible)	85	2	17 $\left(\frac{2}{10} \times 85\right)$
		Total Milestone Grade	**70** (38 + 15 + 17)

ilestone	Milestone Grade (from grading rubric)	Points Earned (distributed among all students who worked on milestone)	Milestone Credit
Engine Tuning (6 points possible)	95	3	28.5 $\left(\frac{3}{10} \times 95\right)$
Intake Fabricated (6 points possible)	75	6	45 $\left(\frac{6}{10} \times 75\right)$
Intake Installed (2 points possible)	85	2	17 $\left(\frac{2}{10} \times 85\right)$
		Total Milestone Grade	**90.5** (28.5 + 45 + 17)

Instructors observed that the milestone points system encouraged struggling students to participate more. Naturally, the students who do not "pull their own weight" receive lower overall milestone grades. The data also shows that these students with relatively low overall milestone grades were also rated low in their professionalism by other students and the instructors. Table 3 shows that the addition of the points system increased the number of students with low overall milestone grades compared to their overall course grade. This indicates that while a student may perform well in their research/design presentations and the final technical report, their lack of contribution to the main tasks of the project is captured by the points system.

TABLE 3: NUMBER OF STUDENTS WITH OVERALL MILESTONE GRADES AT LEAST 6% LOWER (HALF A LETTER GRADE) THAN OVERALL COURSE GRADE

	Summer 2013 (without points)	Summer 2014 (with points)
Students	**2 (out of 30)**	**9 (out of 31)**

The data also shows that the students with overall milestone grades that are at least 6% lower than their overall course grade (Table 3) also receive below average professionalism scores. Of the nine students who received relatively low milestone grades in the summer of 2014, seven of them, 78%, received professionalism scores that were at least 6% below the class average. This correlation shows that the points system was correcting student grades in a direct relationship with student time and effort put into the project as judged by peer and instructor evaluations.

Further evidence shows that the points system holds students accountable to their work by comparing overall milestone grades to professionalism scores across the entire class. Table 4 shows that the percentage of students receiving milestone grades similar to their professionalism scores (by noting if they were both above or below average) increases with the addition of the points system. The points system brings milestone grades more in line with professionalism scores because it captures the amount of individual effort within the shared workload. These two grading metrics, however similar, do not directly overlap. Professionalism focuses on completing work within a team, while the milestone grades stress timely task completion.

TABLE 4: COMPARISON OF OVERALL MILESTONE GRADES TO PROFESSIONALISM SCORES

	Summer 2013 (without points)	Summer 2014 (with points)
Students with high/low grades in both categories	53%	61%
Standard deviation of the difference between milestone and professionalism grades	11.4	10.4

V. EMPHASIS PUT ON RESOURCES FOR RESEARCH PRESENTATIONS

The first day of the capstone course the students were given access to all the summative reports from the past several years of the capstone projects. Understandably, these reports often became the main resource for the research presentations. However, in several instances the only other references included things like the SAE online forums or conversations with alumni who had completed the same project. While these are certainly acceptable sources of information, it was causing the students to focus too much on what was done in previous years without understanding the basic design concepts and continuously improving.

To solve this problem, a simple addition was made to the research presentation grading rubric to address the quality of the sources used. This assessment point was clearly pointed out to the students when the research presentations were assigned. The quality of sources measure was also included in the midterm design review and again its importance was conveyed to the students when the presentation was assigned.

VI. FUTURE PLANS

It has become clear that continuous improvement is necessary in the capstone assessment process. While incremental improvements have been made over the past several years, there is still a level of dissatisfaction among the students taking the course. This is especially evident in the students who spend the most time on the projects during the build semester. The grading system does seem to more accurately reflect the quality of work and commitment of each student, but there still seems to frustration among the more dedicated students.

To address the dissatisfaction of the more dedicated students, two additional changes will be implemented during the next build semester. First, every student is going to be asked to give a five minute progress update for their entire project group each week during the scheduled class time. Each student will be asked to detail what they have accomplished in the previous week, and what they plan to accomplish during the next week. The students will give their notebooks to the course instructors for verification and evaluation during the presentations. The assumption is that each student knowing they will be responsible to the entire group for their accomplishments will help push the lesser motivated students. It is also hoped that this will help the highly dedicated students to realize that even though some of the other students are not spending as much time in the shop, they are still making important contributions to the project.

Another way to try to improve student satisfaction in the projects is to provide them with a little better understanding of the details that need to be completed for the entire project to come together. While the milestones have given students the structure that they need to complete the projects on time, they often do not appreciate all the little details that need to be completed on the way to finishing each milestone on time. To give the students a better idea of what needs to be accomplished, the instructors are going to provide the students with a Gantt Chart laying out the milestone dates with space left for the small details. As a team, the details will be added to the chart at the beginning of the semester. The chart will then be referenced at the end of each weekly meeting and altered as necessary. The only thing that will not be permitted to change will be the milestone evaluation dates. The goal is to again give students a little more appreciation for what everyone is doing, while letting them have control over the planning of each small step in the process. The Gantt Chart will then become a living document that will be passed down from year to year.

VII. SUMMARY AND CONCLUSION

The development of the student assessment for the capstone course sequence is an ongoing process. Many improvements have been made over the past several years, and there is still much room for improvement.

The introduction of milestones into the capstone course sequence was a significant improvement and helped ensure that the projects would be completed on schedule and provide sufficient time for testing and debugging. It was necessary to implement a late penalty system to hold students responsible for their chosen milestones, even if they were not completed by the original due date. The combination of project milestones and late penalties improved the quality of the projects by increasing the amount of time available to test the vehicles before the competition date.

A point system was implemented to adjust final milestone grades according to the amount of work that each student contributed to the major tasks (milestones) throughout the semester so that course grades better reflected student performance. Students who contributed more/less received a proportional increase/decrease in their overall milestone grade (25% of the final course grade).

A smaller improvement was made by putting an emphasis on using reputable sources for research presentations. This was accomplished by emphasizing to the students that the grading rubric would include a judgment of the quality of their sources.

The next set of proposed improvements to the capstone assessment system includes adding individual progress reporting each week and better use of a Gantt Chart to keep students aware of the progress of the entire project. The focus of these changes is to improve student awareness and communications, thus improving student satisfaction.

REFERENCES

[1] Mechanical Engineering Program Curriculum, York College of Pennsylvania,< http://cagtalog.ycp.edu>.

[2] "Formula SAE", Society of Automotive Engineers, <http://students.sae.org/competitions/formulaseries>.