Using Continuous Peer Evaluation in Team-Based Engineering Capstone Projects: A Case Study

Wilhelm A. Friess and Andrew J. Goupee

***Abstract*—Scholarship of Application.**

***Background:* Capstone courses constitute the culminating experience in engineering curricula. A core characteristic is the student team and project-based nature, with many team deliverables. The ensuing difficulty is to fairly assess the individual team member's contribution toward the team effort.**

***Contribution:* The method presented here is based on weekly peer evaluation of the individual team member's contribution, which subsequently yields a participation factor (PF), in turn scaling the team grade in accordance with the individual student performance.**

***Intended Outcome:* This method allows the timely adjustment of the individual student effort to match the group expectations and rewards high-performing students by making higher individual grades than the team average possible, while penalizing underperforming free riders by not benefiting from other student's performance.**

***Application Design:* The method allows students to continuously calibrate their own and their teammate's expectations and improve their peer score by adjusting their individual efforts. This feedback also requires students to practice professional communication, and in particular giving and receiving critical feedback, and thus is highly aligned with industry needs.**

***Findings:* Results evaluated over three iterations of the assessment process indicate a weak positive correlation (0.26) of the peer evaluation with the individual instructor-graded deliverables as well as the individual student grade point average (GPA, 0.23). Further, survey-based data indicate student agreement that the PF is a fair reflection of the individual performance, and a neutral perceived overall assessment system effectiveness, with reported primary barriers being the difficulty in assigning fair peer grades and of open, critical discussion.**

***Index Terms*—Grading systems, project-based learning, senior design, student assessment, teamwork, undergraduate education.**

I. Introduction

CAPSTONE experiences constitute a core curriculum requirement for engineering students. The ABET requires engineering curricula to prepare students for engineering practice "through a curriculum culminating in a major design experience based on the knowledge and skills acquired in earlier course work and incorporating appropriate engineering standards and multiple realistic constraints" [1]. ABET's student outcomes (SOs) require students to demonstrate "an ability to function on multidisciplinary teams" or, as more recently defined in the revised SOs, "an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives" [1]. The capstone course or sequence is ideally suited and often utilized to provide these experiences [2]. However, a difficulty that many institutions experience in the context of not only capstone but any experience that requires team activities, is how to assess the individual performance of a student within a student team. These experiences range from secondary education [3], to university [4]–[7], to industry [8].

In the higher education context, the assessment of individual performance in a team environment is important not only to satisfy ABET's requirement but also to institute a "fairness" for all participants that often is directly related to successful team dynamics [9]. This difficulty has triggered the development of a capstone project assessment system that incorporates continuous peer evaluation as a principal mechanism to fairly and effectively assess the individual contribution to a directly assessed team deliverable.

The research literature reinforces that team effectiveness is rooted in overcoming core difficulties of conflict management[1] [2], [10], [11], with the underlying challenge of dealing with "free riders." Free riders are those students who do not contribute to the team effort under the expectation that the remaining team members will ensure that they receive a good grade [2], [4]. The key to addressing conflict arising from free riders is an assessment system capable of identifying individual contributions toward the team effort [12]. Free riding is also often not a premeditated attitude, but one emerging from decreasing motivation to participate [2]. In accordance, timely and continuous feedback on the individual performance (as opposed to summative feedback only [5], [11]) enables students to develop a response by continuously calibrating their effort with team expectations and adjusting their attitude and participation. While periodic instructor feedback represents a core component in such an assessment system, it is limited as it cannot explore the internal team dynamics to the extent that the team members can. Thus, peer evaluation constitutes an often utilized mechanism to offer fair grading of individual contribution to team deliverables [4]–[6], [11], [13], [14].

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The authors are with the Mechanical Engineering Department, University of Maine, Orono, ME 04469 USA (e-mail: wilhelm.friess@maine.edu).

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[1]At the University of Maine Mechanical Engineering Capstone, Tuckman's stages are taught to the students to prepare and anticipate conflict, coupled with individualized coaching of the teams.

Extensive literature exists on different forms and the overall effectiveness of peer evaluation in a variety of contexts. Van den Bogaard and Saunders-Smits [11] reviewed three different summative peer evaluation methods utilized at two European and one Australian universities, analyzing the differences in the cultural context and its impact on peer evaluation effectiveness. Adenso-Díaz *et al.* [8] reviewed summative peer evaluation approaches in the context of construction management coursework, with results that confirm their effectiveness in addressing the above-mentioned teamwork challenges. Fellenz [14] introduced the Group Peer Evaluation Protocol, which is a quasi-summative peer evaluation system utilized in management education, that scales the group deliverables weighted to the individual student performance. Mina and Holland [15] described a model for managing multidisciplinary capstone projects and recognized the need for frequent peer evaluation, which is further reinforced by Aggarwal and O'Brien [16], who report that "social loafing" on group projects is reduced with multiple peer evaluations during the course. Karn and Cowling [10] presented a similar method to the one presented here in the context of software engineering capstone, however with only summative peer evaluation frequency with limited opportunity for the adjustment of the individual student's effort in response to the team expectations. Van den Bogaard and Saunders-Smits [11] have developed an assessment system toolkit that includes three peer assessments throughout the semester, and their reported student perceptions support the results presented here.

The method presented here constitutes a combination of reported best practices, with a focus on creating a process that allows students to adjust their effort to match the group expectations. The method also allows high-performing students to exceed an otherwise potentially mediocre team average, and at the same time penalizes free riders by making it impossible to benefit from the team average performance. The method deliberately requires open discussions and professional communication among the team members, to develop an ability to give and receive critical feedback, which according to [17] reflects high-order skills on Bloom's taxonomy and is of high value in the workplace.

II. Objective and Methods

The objective of this article is to implement and evaluate a team project assessment technique that allocates individual grades based on the individual team member participation. The scheme utilizes continuous peer evaluation to assess individual performance in the team context and provides the means to scale the grades to reflect this individual contribution. In order to validate the approach, the perceived effectiveness of the method is reported, as well as the correlation of the peer evaluation results with directly assessed individual student work.

The capstone at the University of Maine is a sequence of two courses (4ch in Fall and 3ch in Spring), and it constitutes a key element in the assessment of the ABET learning outcomes. Three out of the ten capstone course learning outcomes either directly or indirectly reflect the need for teamwork skills.

1) The ability to function on a multidisciplinary team.
2) Professionalism and ethical responsibility.
3) Communications (oral and written).

This need is also reflected in the course objective: "All students are required to work in teams and within the course guidelines so as to maximize the interpersonal and planning experience as a part of the class," and specific lectures on teamwork and team design processes are offered early in the first semester and on an as-needed basis throughout the year. In addition, the course learning outcomes directly address the need for the students to learn to give and receive critical feedback, and this outcome is incorporated into the design of the assessment system presented here.

The course has two 1-h lectures each week, during which design and teamwork topics are covered as well as guest lecturers hosted, and weekly meetings of each team with the instructors to discuss challenges and progress made.

The principal course milestones are evenly distributed over the course of two semesters, and are as follows:

1) *Semester 1:* problem definition and conceptual design;
2) *Semester 1:* detailed design and CAD package;
3) *Semester 2:* manufacturing and operational handbook;
4) *Semester 2:* design testing and evaluation.

The overall grade for the course sequence is split into two portions: 1) an individual component (worth 40% of the semester grade) and 2) a team component (worth 60% of the semester grade.) The 60–40 split was chosen by the instructor team for two reasons.

1) The split reflects the primary teamwork nature of the course, however giving appropriate credit for the significant effort needed for the individual deliverables, some of which are designed in response to additional ABET performance indicator assessment needs.
2) This split provides adequate grade sensitivity to the participation factor (PF) outlined below and that acts as a multiplier to the team portion of the grade.

The individual deliverables include four papers in addition to four individually assessed presentations during the design reviews (split evenly over both semesters). The team deliverables are composed of four team reports that reflect the project design and test phases, as well as a CAD package, a team folder, and an open house presentation.

The assessment utilizing the peer grading approach presented here builds on a number of reported peer evaluation systems [5], [6], [14], [15], [18], and incorporates two core characteristics.

A. Continuous Assessment

The process requires students to provide high-frequency (weekly) peer evaluations, thereby increasing transparency and providing each student with an ongoing performance evaluation in the context of their participation. The desired effect of this is that students incrementally develop a clearer vision of their work expectations, and have

TABLE I
CONTINUOUS PEER ASSESSMENT SCORING RUBRIC

Score: 0	*1*	*2*	*3*
The team member has not done the assigned work	*The team member has completed a small portion of the assigned work*	*The team member has completed most of the assigned work, or all the assigned work but incorrectly*	*The team member has completed all assigned work correctly.*

enough time to react to adjust their performance to these group expectations before summative grading.

B. Peer Score Used to Compute Participation Factor

The peer score is not used directly as a grade item in the assessment formula, but rather to compute a PF that indicates the level of participation of the individual in the team effort. This PF then scales the traditionally graded team deliverables to compute an individual team score. The advantage of this system is that the individual peer grade is normalized by the average team peer grade (of all members), which is indicative of how "functional" the team is. This means that PFs greater than one can be obtained by high-performing students that "carry" the team. This, in turn, allows these students to convert an otherwise mediocre team grade obtained by inadequate performance of some team members into an individual grade that exceeds the mediocre team grade, in a true reflection of their actual performance. It is in the interest of the students to be fair in the peer evaluation process, as giving a higher than merited peer grade not only affects the peer's grade but also the grading student's grade by artificially inflating the team average (and thus reducing one's own PF).

The continuous peer assessment is highly structured and conducted in the required weekly team meetings, where each team is required to produce clearly formulated team meeting minutes (TMMs) signed and approved by all team members. These minutes follow the following format.

1) Review of the previous week's work from each team member.
2) Peer evaluation of the work of each team member using the rubric presented in Table I.
3) Discussion on the status of the project, problems, and challenges, and updating the Gantt chart and project timeline.
4) Team sets individual specific, measurable, attainable, realistic, and timely individual goals, within the scope of the required course time commitment.

In addition to the scoring rubric above, each team member needs to provide a written justification for this score that is reviewed periodically by the instructor team. Students receive specific training at the beginning of the semester on how to conduct these team meetings in a professional and respectful manner, and use templates to write their weekly TMM.

Formulating specific, measurable, attainable, realistic, and timely individual weekly deliverables is a critical element in this process, as they provide the measure for the team member's assessment and evaluation of the following week. This process facilitates transparency in the teamwork process, and continuously provides a calibration instrument for each team member with regards to the team's expectation. It is important to emphasize that the team expectation needs to be aligned with the course time commitment and scope, and the instructors oversee this constraint in biweekly instructor meetings with the teams to ensure that teams do not over or underchallenge themselves. The results of this peer evaluation process are then utilized by the instructor to compute an individual grade from the team component using the following formula:

$$\text{Final Individual Grade} = 40\% \cdot \text{IG} + 60\% \cdot \text{PF} \cdot \text{TG} \quad (1)$$

where IG is the individual grade obtained from the individual deliverables, PF is the peer-grade-based PF, and TG is the grade that the team has obtained from the team deliverables (team grade).

The PF is obtained as follows:

$$\text{PF} = \frac{\text{Average individual peer grade}}{\text{Average peer grade all team members}}. \quad (2)$$

C. Example Calculation and Application

Cases 1 and 2 below represent hypothetical cases to illustrate the sensitivity of the method. The actual assessed statistics are presented in Section III.

1) Case 1—The Free Rider: The student discussed here chooses to put the effort in and submit all individual deliverables (example individual grade of 95%), however does not participate in the team activities under the expectation that the remaining four team members will obtain a high team grade. An example of peer score for this student is 10%, with an average team score of all the team members of 82%, obtained from averaging the underperforming student score with all remaining four team members attaining 100% team score. This results in a PF of 0.12 for the free rider (2). The resulting team deliverable has suffered from the inactivity of the free rider, receiving a grade of 85%. Thus, the free riders final team score will be $0.12 \times 85\%$, equaling 10%. The final score of the free rider is then computed using (1), resulting in an F grade (44%), in fair representation of the student's work effort.

2) Case 2—The Lone High Performer: The student described here is the workhorse of the five people, continuously making up the work that other students have failed to contribute. An example individual score of this student is 100%, with a peer score of 100%. Due to the low performance of the remaining team members (with peer score of 75% each), this student's PF is 1.25 which, again considering a poor team deliverable due to the inactivity of most of the group (assume a 75%) will give the high performer an individual team score (1) of 94%, resulting in an overall grade of A (96%), even though the team deliverables suffered from the inactivity of much of the group.

The above examples illustrate that the scheme will compensate for inactive team members by allowing high performers to exceed the grade obtained by the collective. In turn, it penalizes free riders, not allowing them to rely on the other group members' effort. A fundamental requirement for the scheme is

TABLE II
PF STATISTICS

Semester	Fall 2017	Spring 2018	Fall 2018
n	75	74*	84
COV	3.77%	4.02%	4.23%
Maximum	1.061	1.085	1.087
Minimum	0.842	0.823	0.845
Range	0.219	0.262	0.242

*One student did not return for the Spring 2018 semester.

a fair peer evaluation within the team. In this implementation, the peer evaluation requires nonanonymous open discussion among the team members which simulates an industrial environment. This open and sometimes critical communication requirement, while being considered by the instructors to be an essential learning outcome for successful preparation for industry, represents the biggest hurdle for individual student peer assessment, as presented in the results.

III. Results and Discussion

The data presented here originates from data collected during the Fall 2017, Spring 2018, and Fall 2018 semesters. The total number of unique student participants is 159 (75 for Fall and Spring 2017—the same students took both courses—and 84 for the Fall 2018 course), and the combined survey response rate was 42.3%.

A. PF Statistics

Provided in Table II are the statistics for the PF over the three semesters spanning Fall 2017 to Fall 2018, with n denoting the number of students in each semester. A few key observations can be made from PF statistics alone. As observed from the fairly low coefficient of variation (COV) and PF range, it is apparent that students tend to avoid assigning very low peer scores in TMM. However, the same cohort of students in the 2017–2018 academic year exhibited an increase in the PF COV (from 3.77% to 4.02%) and an increase in the PF range by 19.9% moving from the first to the second semester. This indicates that students were more willing to provide lower grades for their teammates' performance in TMM as the capstone experience progressed. In the Fall of 2018, the additional instructional emphasis was placed on anticipating, and dealing with team conflicts. This may be one of the causes for the increased PF COV and range for the first semester (Fall 2018) of the second cohort as opposed to the first semester of the first cohort (Fall 2017).

Fig. 1 shows the evolution of the average peer grade overall students averaged over the sampling period (Fall 2017, Spring 2018, and Fall 2018). Students start strong, but then typically lose some dedication as the semester progresses and the workload increases. This decrease however is not sustained, as students calibrate their required effort throughout the semester, and then rebound toward the end of the semester with a final effort. This dynamic is supported by instructor observations. While not directly assessed here, it is the instructor's perception that the requirement to openly discuss expectations and give and receive constructive criticism within a team on a weekly basis, in addition, to provide a realistic

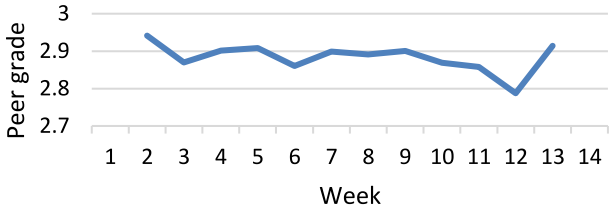

Fig. 1. Average peer grade progression over sampling period.

TABLE III
CORRELATION OF PF TO STUDENT INDIVIDUAL WORK AND OVERALL GPA

Semester	Fall 2017	Spring 2018	Fall 2018
Correlation to individual deliverable	0.444	0.129	0.198
Correlation to student GPA	0.296	0.198	0.194
Correlation to student reported time on task	0.600	0.684	0.382*

*Only 5 out of 12 weeks of data were available for this semester.

industry experience, supports this continuous adjustment of the individual effort, and makes "disconnecting" from the team more difficult.

B. Correlation of PF With Individually Graded Deliverables, Overall Student GPA, and Time on Task

In order to evaluate, if the students who perform at a high level in the individual work also perform better in the team environment, the correlation of the grade attained by the individual student deliverables and the correlation to the student's grade point average (GPA) is computed and shown in Table III. The results indicate a correlation, albeit modest, between the PF scores and the individual student performance in the directly assessed individual deliverables (correlation coefficients of 0.129 and higher). The table also shows a similar correlation is obtained between the PF and student GPAs. It should be noted that the correlation coefficients are not anticipated to be extremely high, as the individual performances and GPAs on a team could theoretically all be quite high or quite low, but the average PF of a team resulting from (2) will always be 1. As such, high-performing students on very good teams can (and do) end up with PF values less than one, and conversely, poor-performing students on underperforming teams can (and do) achieve PF values greater than one. An additional validation measure is the individual time students spend on the task, and that they are required to log. The correlation of the PF with time on the task is also reported in Table III.

C. Student Feedback on Teamwork Challenges

Using an anonymous summative survey, students report on their perceived satisfaction with the system, the perceived barriers, as well as the perceived effectiveness toward improved team performance. But first, the survey inquired if teamwork truly represented a challenge, with strong positive results as shown in Fig. 2. 79 out of 99 survey respondents (80%)

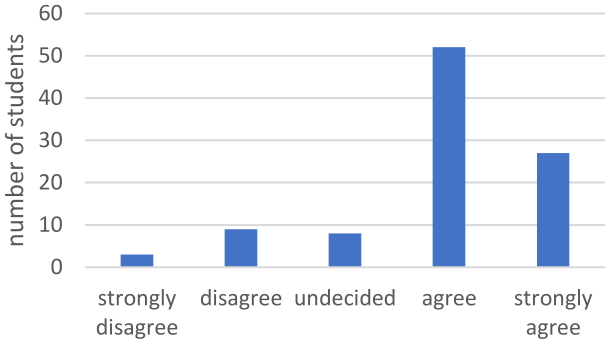

Fig. 2. Student response to survey question "I have encountered teamwork challenges throughout the semester."

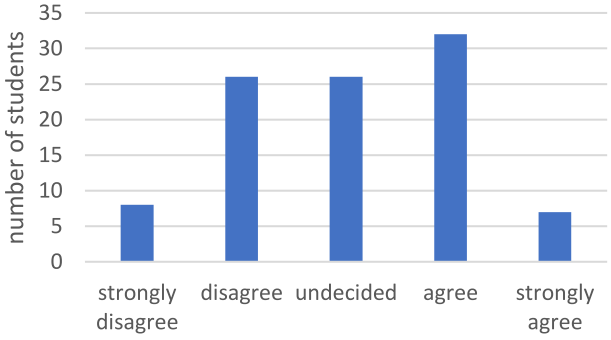

Fig. 3. Student response to survey question "I think the peer evaluation process has been an effective tool for addressing teamwork challenges."

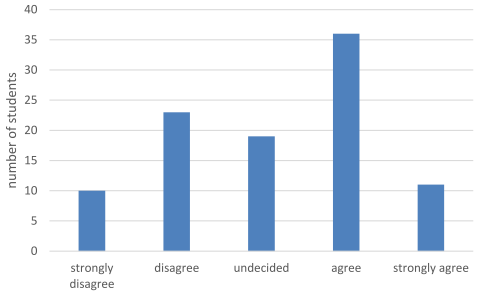

Fig. 4. Student response to survey question "The PF reflects my individual performance relative to my teammates."

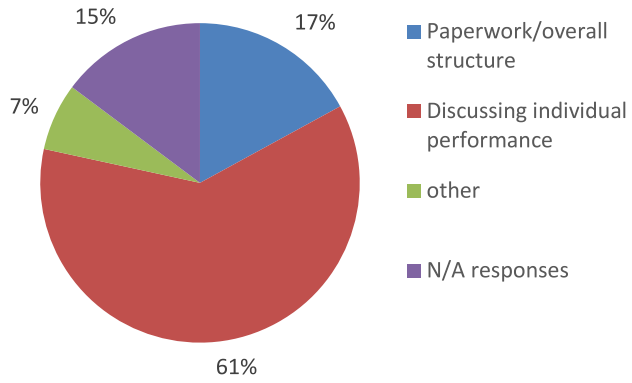

Fig. 5. Coded student responses to question "What are the biggest barriers you see to the peer evaluation process."

over the three semesters indicate that they have experienced teamwork challenges.

D. Perceived Effectiveness Toward Improved Team Performance

As evidenced by the survey results provided in Fig. 3, students perceived that the peer evaluation process was somewhat effective in dealing with teamwork challenges. Over 39% of respondents agreed or strongly agreed that the peer evaluation system was effective for addressing team challenges. However, 34% of respondents disagreed or strongly disagreed with the effectiveness of the utilized approach.

When asked if the PF obtained by a student from the peer evaluation process reflected their individual performance relative to their peers, the survey results tended to improve. As shown in Fig. 4, nearly half (48%) of students agreed or strongly agreed that the PF reflected their individual performance relative to their teammates, with 19% undecided and 33% disagreeing or strongly disagreeing.

Instructor observations regarding the effectiveness of the peer evaluation process include the following.

1) Students are not used to providing and receiving critical feedback and show some reluctance toward this "uncomfortable" yet very important activity. A current work in progress is to expand the training in the fall semester to support students in becoming comfortable with these activities. This training will provide the teams moderated opportunities to practice conflictive discussions and build their awareness of the need for a professional interaction and attitude. The feedback received from graduates in the industry strongly supports the importance of the ability of giving and receiving nonanonymous feedback.
2) The required peer evaluation, structured weekly meeting and associated paperwork can be perceived by some high-outcome-driven students as burdensome, taking away time better spent on the project. This is often observed in students that still need to develop their appreciation of project planning, which is a learning outcome of the course. The training elements outlined above, in combination with an increasingly professional capstone lab environment will support their appreciation of this important component of every project.
3) The instructor observations support the effectiveness of the peer evaluation process. The instructor team's continuous student interaction during the capstone class and lab and the biweekly individual team meetings, allows them to get to know every individual student and the team dynamics, and based on these observations the PF obtained through the peer evaluation process accurately reflects individual performance.

E. Perceived Barriers

Coded student responses to questions pertaining to the peer evaluation process barriers are provided in Fig. 5.[2]

[2]Only completed responses are shown; 24% of respondents skipped this question or provided "N/A" as a response.

While 17% of students indicated concerns regarding the book-keeping and structure of the TMM process, the majority of responses (61%) noted issues with openly and honestly discussing an individual's performance during team meetings.

It is clear that while becoming competent in a critical discussion environment is beneficial for the workplace, it also represents the biggest perceived hurdle for effective peer evaluation to the students (although the previous results indicate that students agree that the PF is representative of their effort in the team). These results suggest that students are reluctant to openly and professionally express constructive criticism, but at the same time agree that there is a benefit to doing so. This fact is confirmed by instructor observations and informal student feedback where students, and often in hindsight, manifest the value of having learned to communicate professionally and to express constructive criticism in a team environment.

IV. Conclusion

The assessment of individual contribution within a team-based project setting remains a challenge. The assessment system presented here is characterized by the scaling of the team deliverables based on a PF obtained through continuous peer assessment. The continuous nature of the peer assessment supports timely student response allowing them to calibrate their individual effort to the team expectations, and the application of the PF to the team deliverable grade enables the fair scoring of both performance extremes; the lone high performers and the free riders. In addition, the method requires open and critical team communication, in support of industry preparation.

Results indicate a weak positive correlation of the peer scoring (and thus the PF) to the individual student performance as obtained from individual deliverables and the student's GPA. Results also indicate a neutral perceived effectiveness by the students of the peer assessment system, however, a positive perception of the accuracy of the PF to their individual performance. The primary perceived barrier to better effectiveness of the assessment system is the requirement to conduct open discussions within the team, and the need to give and receive constructive feedback.

In conclusion, the presented system is capable of assessing individual contributions in a team project, facilitates team formation and operation by requiring continuous team-internal feedback, and generates a transparent grading system where students know at all times where they stand. Future developments will focus on improving this communication capability, both within the capstone sequence and by analyzing prior curricular opportunities.

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