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Influence of Group Learning in Environmental Engineering: A Curriculum and Course-level Assessment

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Abstract

The distribution of graded assignments, and the points available therein, was studied across 14 of our institution's junior- and senior-level environmental engineering courses. Several of the courses studied incorporated teamwork as a stated course objective or a student learning outcome, while many instructors separately chose to implement teamwork as one of their stated teaching methods. Point distribution, whether on assignments submitted by individual students or those by groups or teams of students, varied by course based on several factors, including teamwork as a stated course objective or peer learning as a priority for the course instructor. For our ABET-accredited Environmental Engineering major, achievement of ABET Engineering Accreditation Commission (EAC) Student Outcome 5 was also a factor, with teamwork incorporated on graded assignments to achieve ABET EAC Student Outcome 5. Courses with labs and sizeable design projects, especially those tied to ABET EAC Student Outcome 5, had a much larger fraction of team-based activity points than those without labs or large course projects. To examine teamwork as a teaching method, an evaluation of student grades indicated that team-based activities did not equally benefit all students, with lower performing students receiving a larger grade benefit. In similar fashion, group learning exercises did not significantly improve student learning for subsequently administered individual exams. When student learning related to team selection methodologies were examined within a large enrollment course, it was concluded that students who selected their own teams earned grades that mirrored their overall course grade. Lower performing students who were randomly assigned, or purposefully grouped with higher performing students based on previous performance, typically earned higher grades on the group assignment than other events in the course. However, the increased grade in these cases did not consistently reflect improved individual performance.

Keywords: team grading; team-based learning; team selection; group projects; assessment

1. Introduction

Group work, commonly referred to as cooperative learning [1], is an essential aspect of an undergraduate engineering experience because it is required to prepare graduates for professional practice [2]. Educators have striven to create and document efficacious, unbiased, and rewarding cooperative learning experiences as more than 300 papers were published on this topic between 1960 and 2003 [3] and more have followed. Nevertheless, a process for creating an optimal cooperative learning experience remains elusive [4].

Use of grades to quantify student learning is generally considered an essential aspect of education [5], [6] and selected grades can be a valuable element in continuous improvement processes [2]. However, the ubiquitous usage and benefits of grades in higher education has been disputed [7]–[9] including applications in cooperative learning interventions [10]. For example, it has been argued that grades should be eliminated because they do not reflect student learning in a group setting [11] and educators should, instead, focus on optimization of

cooperative learning outcomes in the absence of grades [10]. On the other hand, novel approaches to effectively apportion grades in cooperative learning interventions continue to be developed [12]–[15], while students typically report that a single group grade is considered the evenhanded approach [16], [17]. Tucker and Abbasi [18] reported that students' dissatisfaction with underperforming peers was the most significant aspect of how they assessed the fairness of assigned grades in cooperative learning engagements. Although it is analogous to group work in professional practice (and professional team sports), assignment of the same grade to all members of a student group has not resulted in an equal provision of effort by each member [4]. Under-performing students are common in cooperative learning experiences [4] and they have been characterized by Coppit [19] as follows: those that seek to maximize their grade while minimizing the amount of work that they must complete; those that do not perform their full share of the work and are satisfied with a lower grade; those that attempt to do their fair share of the work but at the last minute; and those that participate in many aspects of the project but only in a superficial way. On the opposite end of the performance spectrum are students who attempt to complete the project by themselves and students who attempt to help underachievers obtain a higher grade [19]. Numerous approaches that aim to create amicable and productive groups, considering the student character traits described above, have been proposed [12]. However, a process that can consistently produce optimal groups and assess student work in a perceived (by students) unbiased approach appears to be elusive [4], [18].

Our environmental engineering program offers a graded cooperative learning experience in nearly every course. We hypothesized that student intragroup grades on some of these assignments may have been awarded unevenly in cases where students' potential and participation were wide-ranging. Analysis of team-based graded events and individual final course grades was used to test this hypothesis. In addition, an analysis of individual grades, before and after a cooperative learning experience using various means of team formation, was used to explore the influence of group learning on individual performance (and perhaps learning).

2. Methods

The environmental engineering program examined in this study is accredited by the ABET Engineering Accreditation Commission (EAC). ABET EAC has seven Student Outcomes designed to prepare graduates to enter the professional practice of engineering [2]. ABET EAC Student Outcome 5 states that students must have "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" upon graduation. To provide opportunities for our students to develop teamwork-related skills, our major integrates team-based assignments into many of our 14 environmental engineering courses. Prior to this study, our program had never holistically examined the point distribution between team-based and individual assignments across all 14 courses (Table 1).

Table 1. Team and Individual Point Distributions across Environmental Engineering Courses. All courses in our program have 1000 total points possible. Lab courses are underlined. Courses selected to support ABET EAC Student Outcome 5 (Teamwork) are bolded.

Course	Title	Individual Pts	Team Pts	Fraction Team Pts [%]
EV300	Intro to Environmental Science	750	250	25
EV301	Environmental Science for Engineers	880	120	12
EV350	Intro to Environmental Engineering	740	260	26
EV394	Hydrogeology / Hydraulic Design	735	265	26.5
EV396	Environmental Biological Systems	715	285	28.5
EV397	Air Pollution Engineering	900	100	10
EV401	Physical and Chemical Treatment	750	250	25
EV402	Biochemical Treatment	675	325	32.5
EV450	Environmental Eng. for Community Development	700	300	30
EV481	Water Resources Planning	640	360	36
EV488	Solid and Hazardous Waste Remediation	670	330	33
EV490	Environmental Engineering Design	360	640	64
EV491	Advanced Environmental Engineering Design	200	800	80
XS391	Environmental Chemistry	1000	0	0

After examining the point distribution between team-based and individual assignments for the 14 environmental engineering courses within our program, two datasets were evaluated. The first was a course-level analysis that assessed historical data comparing individual and team-based graded events from across several courses to isolate group learning effects on individual performance. The second dataset, a team-selection analysis, was evaluated from a single large enrollment course to assess the effect of different team formation methods on individual performance in group learning.

2.1 Course-level Analysis

Four required courses within the Environmental Engineering major were selected for course-level analysis (Table 2); each occurring in one of the final four semesters of a student's environmental engineering program curriculum (i.e., Terms 5, 6, 7, and 8 within a four-year program). Graded events were identified as either individual or group-based events; two distinctly separate final course grades were then determined for each respective student with one final grade incorporating only individually-based graded events while the second final course grade included both individual and team-based graded events. Two linear least squares regression analyses (see Section 3.2) were performed on this dataset as a function of the individual grade: (1) the difference between the final grade incorporating both individual and team-based graded events and the final grade incorporating only individual graded events; and (2) the percent improvement on exams before and after the group learning exercises.

Table 2. Summary of dataset used in the course-level and team-selection analysis. "Term" represents the respective semester of each course within a representative student's four-year environmental engineering program.

Course	Term	Group Graded Events / Total Graded Events [%]	Number of Students
EV301	5	12	35
EV401	6	25	10
EV488	8	33	19
EV490	7	64	19
EV450*	8	30	153

*EV450 course-level analysis is discussed in the team selection sections (2.2 and 3.3)

2.2 Team-Selection Analysis

A large enrollment course (EV450; Table 2), comprised of students from a wide range of majors at the institution, was split into sections taught by four separate Environmental Engineering faculty. Three methods of team selection within this course were evaluated in the team-selection analyses: (1) self-selection; (2) random selection; and (3) grade-based according to performance in previous courses (Table 3). Each section of the large enrollment course employed a different selection method for team selection. The final "grade-based" method required each team to be comprised of one high-, one medium-, and one low-performing student. Students were categorized as high-, medium-, or low-performing according to their final grade in the prerequisite course, but they maintained autonomy to select their partners provided the team composition requirements were met regarding performance categories.

Table 3. Summary of dataset used in the team-selection analysis.

Team Selection Method	Number of Students	Number of Groups
Self-selection	52	22
Random selection	49	16
Grade-based	52	18

Paired t-tests were used to determine if there was a statistically significant difference in individual exam grades before and after the team learning exercise. Linear least squares regression analysis was performed to identify significant factors on the group learning grade and the final grade in the course as well. Additionally, the linear regression analysis performed in the course-level analysis was repeated for the team-selection analysis for a large enrollment course (see Section 3.3). Unlike the previous course-level analysis, final grades were not divided by individual or team-based graded events for the team-selection analysis due to availability of data for this respective course.

3. Results and Discussion

3.1. Teamwork and Individual Point Distributions in the Environmental Engineering Program

To understand the team and individual point distributions, we surveyed each course within the environmental engineering Program to identify respective team-based and individual assignments (Table 1). In general, more points were allocated to individually executed assignments in all courses except two – our program's design capstone courses (EV490 and EV491). The mean value for team assignment points across all 14 courses was 306 ± 197 points (one standard deviation) out of 1000 total points in the course, or 30.6 ± 19.7%.

Several notable trends are worth discussion. First, courses selected to support ABET EAC Student Outcome 5 (listed as EV481, EV490, and EV491 in Table 1) were the courses that had the highest fraction of team points of all 14 within the program, ranging from 36 to 80% (Table 1). This aligned with our desire to adequately assess ABET EAC Student Outcome 5. Second, our program nests labs within lecture courses instead of requiring students to execute a separate environmental engineering lab course. Each course with nested lab is offered at 3.5-credit hours, as opposed to 3.0-credit lecture-only courses. Our program normally asks students to complete labs and submit reports in teams of 2 to 5 students. Accordingly, lab courses (underlined courses in Table 1) had a relatively high fraction of team points (25-33%) relative to non-lab courses. Further, our program has two courses (EV300 and EV450) that have an in-depth team-based engineering design project and, therefore, had a similar fraction of team points (20-30%) as did lab-based courses. Lastly, the courses with the lowest fraction of team points were courses that were lecture-only (EV301, EV397, and XS391), which ranged from 0-12% team points.

These results suggest that lecture-only courses may innately lend themselves to a lower fraction of team points relative to courses that have team-based labs or design projects. While this result may appear obvious, it is our observation that this type of analysis is not well-published in literature and many programs may not have introspectively examined themselves in this manner. These results further suggest that there is no "standard" fraction of individual points versus team points, but that lecture-only courses (i.e., no labs and no team design project) are likely to have 10% or fewer team points, while lab-based courses or courses with major design projects are likely to have ~25-30% team points and capstone courses can easily exceed 70% team points. The resulting difference in the contribution of team points towards a final grade could have unintended consequences, as we examine in the following sections.

3.2. Course-level Analysis

To target the effect of group learning on final course grades, students' grades were divided into individual graded events and all graded events (i.e., individual and team-based graded events). For each of the four courses included in the course-level analysis, the same general trend was observed; individual-only grades were approximately normally distributed whereas all graded events exhibited a right skewed normal distribution (Figure 1). This suggests that team-based graded events did not equally benefit all students. Previous research in this area identified a similar issue where lower performing students earned improved grades due to group-graded events while higher performing students did not realize improvement [11]. A deep dive into the difference between a student's overall grade (i.e., team-based and individual graded events) and individual grade (i.e., only individual graded events) confirmed that lower performing students received a larger grade benefit than higher performing students (Figure 2). In some cases, higher

performing students saw a worsening on their overall grade due to these group-graded events. Courses where team-based graded events represented a larger fraction of the total grade (>25%) saw a significant impact on final course grades, in some cases >5%.

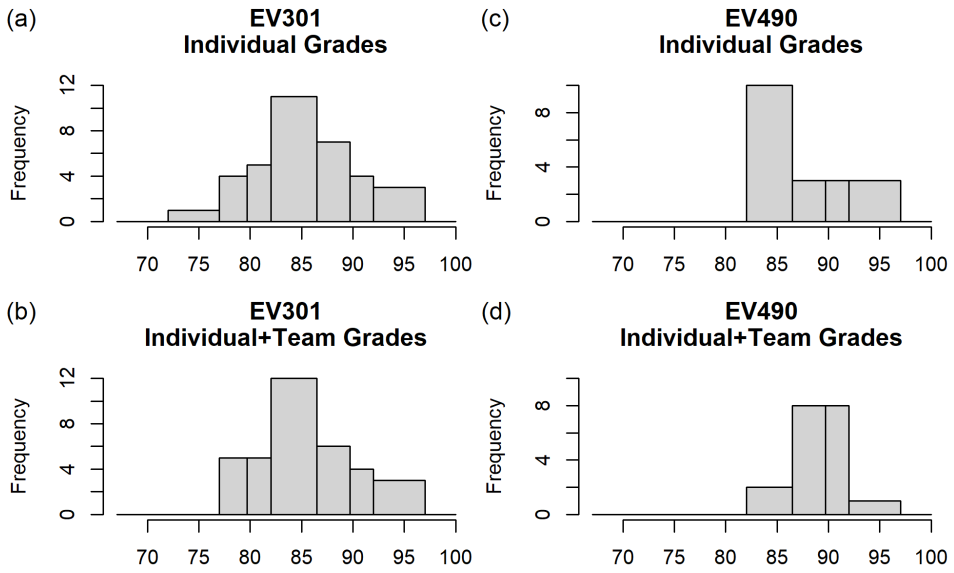

Figure 1. Histograms of a 5th term environmental engineering course (a, b) and a 7th term environmental engineering capstone course (c, d). Separate final grades were calculated for only individual-graded events (a, c) and all-graded events (b, d). Width of bins are based on letter grade ranges.

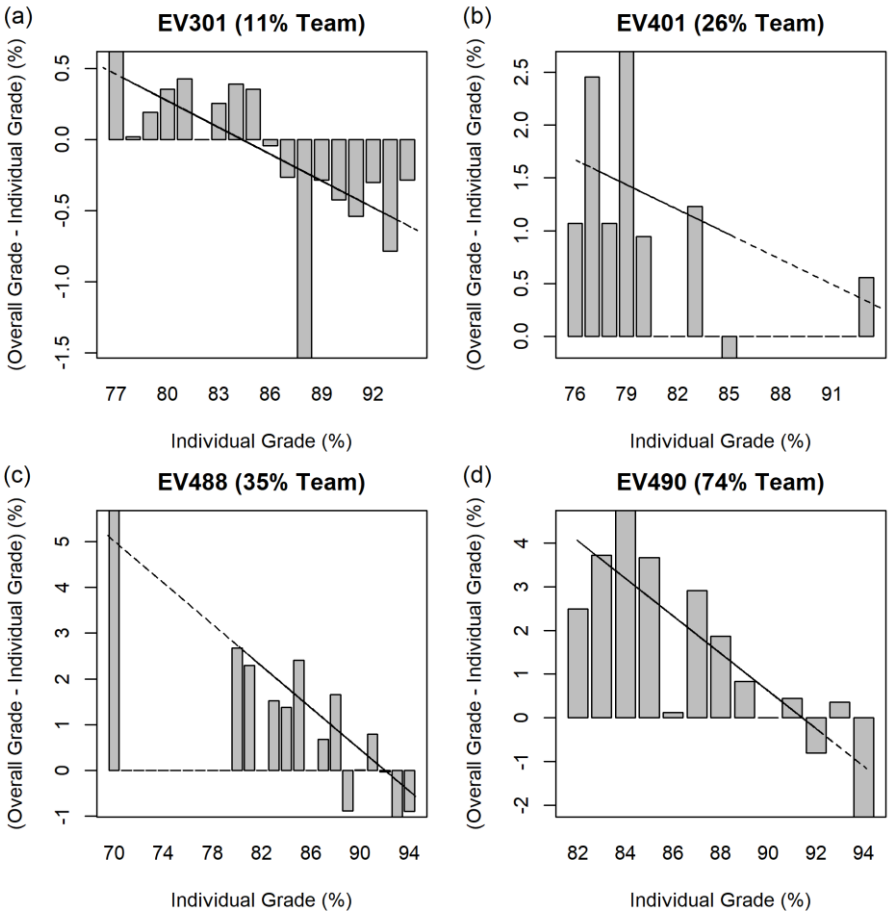

Figure 2. Difference between overall final grade (both individual and team-based graded events) and individual final grade plotted as a function of individual final grade. Differences were averages after rounding to the nearest integer. The linear regression function is considered statistically significant for three of the four courses (EV301: p=7.5e-4; EV488: p=1.2e-7; EV490: p=7.1e-7).

A second analysis was performed to target improvement on individual exams before and after a team-based graded event. Improvement on exams could only be evaluated for three of the four courses, as there are no individual exams in the capstone course (EV490). Of the three courses evaluated, consistent improvement on exams was not identified. Only one course (EV488) demonstrated a statistically significant relationship between exam improvement after the group learning exercise (p=0.02), but it was extremely small (median improvement of 0.036%). Thus, we conclude that the group learning exercises did not significantly improve student learning for individual written exams.

From the course-level analysis, a trend of unequal benefit of group work on students' grades was observed. Higher performing students, based on their final individual grade for the course, generally saw a decrease in their final grade due to group assignments while lower performing students generally saw an increase in their final grade. A possible reason for this observed trend could be team selection. Due to team selection, issues such as variable individual contributions and fractured teamwork processes could exacerbate unequal grade distribution further [18].

Varying the team selection method could be a possible way to mitigate unequal grade distribution between higher and lower performing students within a course (see Section 3.3).

3.3. Team-Selection Analysis

To address the issue of unequal grade distribution and learning benefits observed in the previous section, a large enrollment course (EV450) with a large group assignment between the first and second individual exams was used to explore team selection as a potential equalizer. Similar to the course-level analysis performed in the previous section, team-based grades were not reflective of individual grades in the course (Figure 3.a), or improvement on exams (Figure 3.b). An initial multiple linear least squares regression to predict the team-based activity grade showed significant effects on one type of team selection (self-selection, p=7.8e-5), and lesser, but still statistically significant effects of team size (p=0.03) and one instructor (p=0.02).

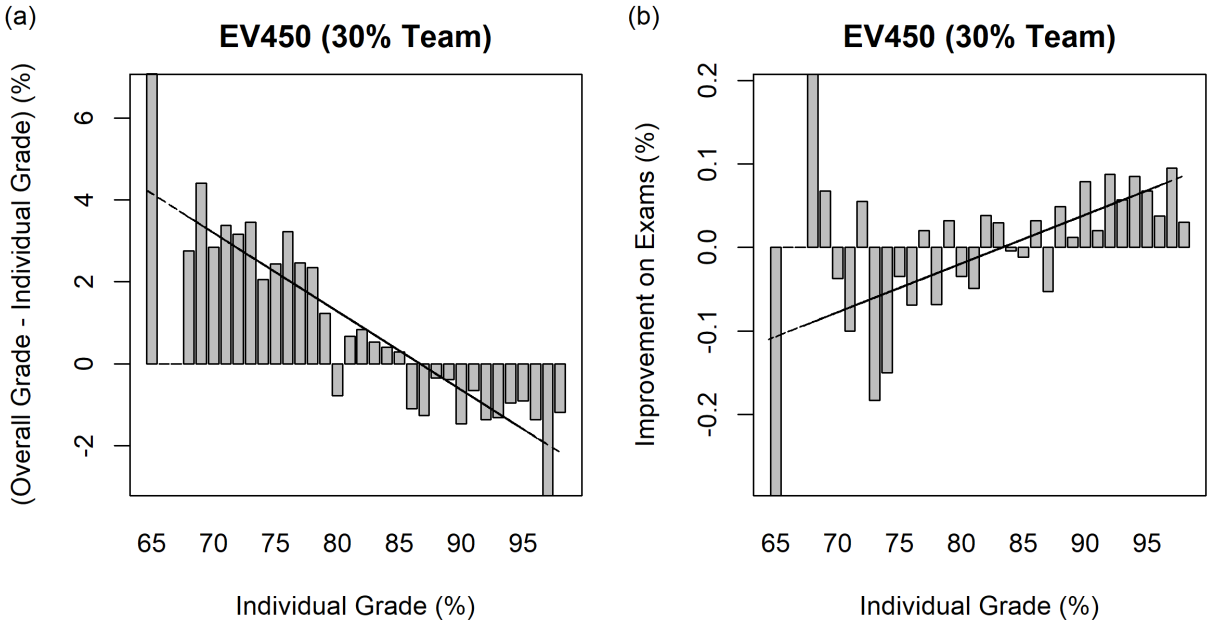

Figure 3. (a) Difference between overall final grade (both individual and team-based graded events) and individual-only final grade plotted as a function of individual-only final grade. (b) Improvement in individual final exams after the group learning exercise plotted as a function of individual-only final grade. Differences were aggregated by averaging to the nearest individual grade. The linear regression function is considered statistically significant (p<2.2e-16 and p=1.7e-8 for [a] and [b], respectively).

When team-based activity grades were evaluated as a function of final course grade, the differences between the team assignment methods were apparent. No statistically significant difference was found between grade-based or randomly assigned teams, however there was a significant difference for self-selected teams. Self-selected teams received grades that mirrored the students' overall grade in the course, but this was not true for grade-based or randomly assigned teams (Figure 4). This observation is supported by previous research, which found that group effectiveness, or the associated event's grade, was correlated to the highest or lowest performing group member depending on the ability of groups to distribute tasks. Many times, similarly-skilled groups of students were found to be more effective than those with students of differing academic acumen [4]. For grade-based and randomly assigned teams, poor performing

students saw higher team-based activity grades that did not necessarily reflect their overall grade in the course. In this study, this disproportionate "grade elevation" was observed for students whose overall course grade was less than 91% and 88%, for the grade-based and randomly assigned teams, respectively. Felder and Brent [12] observed similar results in team-based events, concluding that team-based grade elevation could be avoided by not including team grades for those individuals who are below the passing threshold. While not feasible in every environment, further research may be prudent as to the impact of whether to include team-based event grades for respective teams of students.

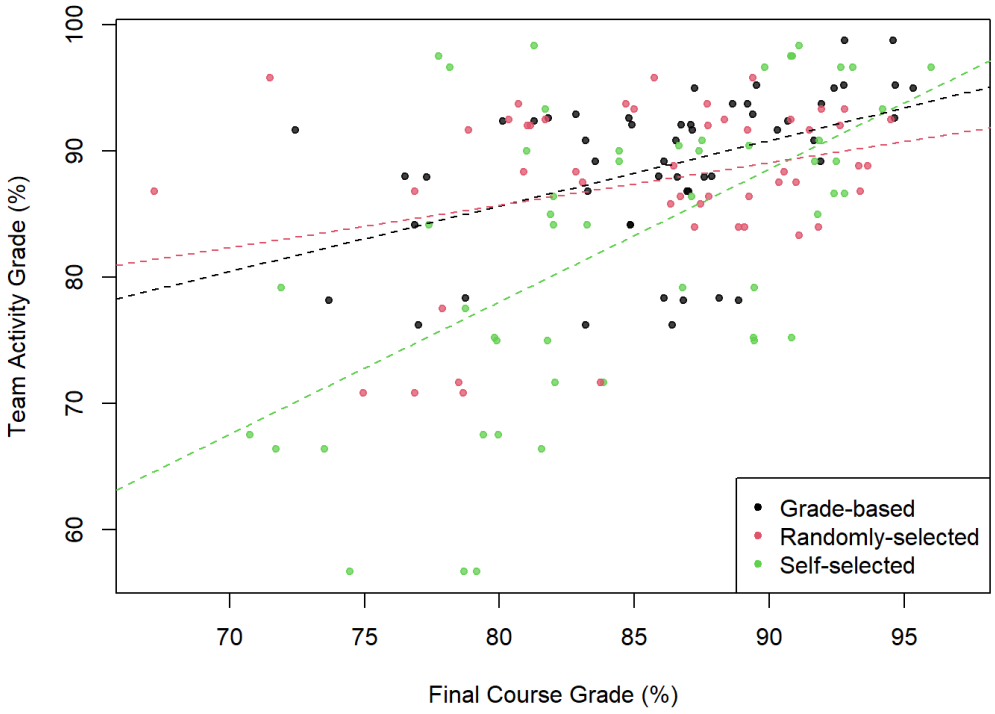

Figure 4. Team-based activity grade plotted as a function of final grade in the course. Linear least squares regression for Grade-based, Randomly-selected, and Self-selected groups were found to be statistically significant (p=6.9e-6, p=6.7e-4, p=0.031, respectively).

To determine if the grade elevation for poor performing students was indicative of additional learning, exam improvement before and after the group activity was evaluated similarly to the team-based activity grade. The average improvement in exam grade was 4% across all students (Figure 5, gray line). If the high team-based activity grade for poor performing students was a measure of increased learning, the average improvement for these groups should be above the mean. However, this was not found to be the case. Grade-based and randomly assigned teams saw no trends in exam grade improvement as a function of overall course grade (Figure 5, black and red lines). Instead, the self-selected teams saw a statistically significant difference in exam grade improvement as a function of overall course grade (p=0.0002). This comparison illustrates that the additional learning incited by the team-based activity was not measured in the team-based activity grade itself. In addition, it follows that the method used to select teams in this activity directly impacted learning that was similarly unable to be measured by the team's grade. Rather, other assessment mechanisms should be considered [13].

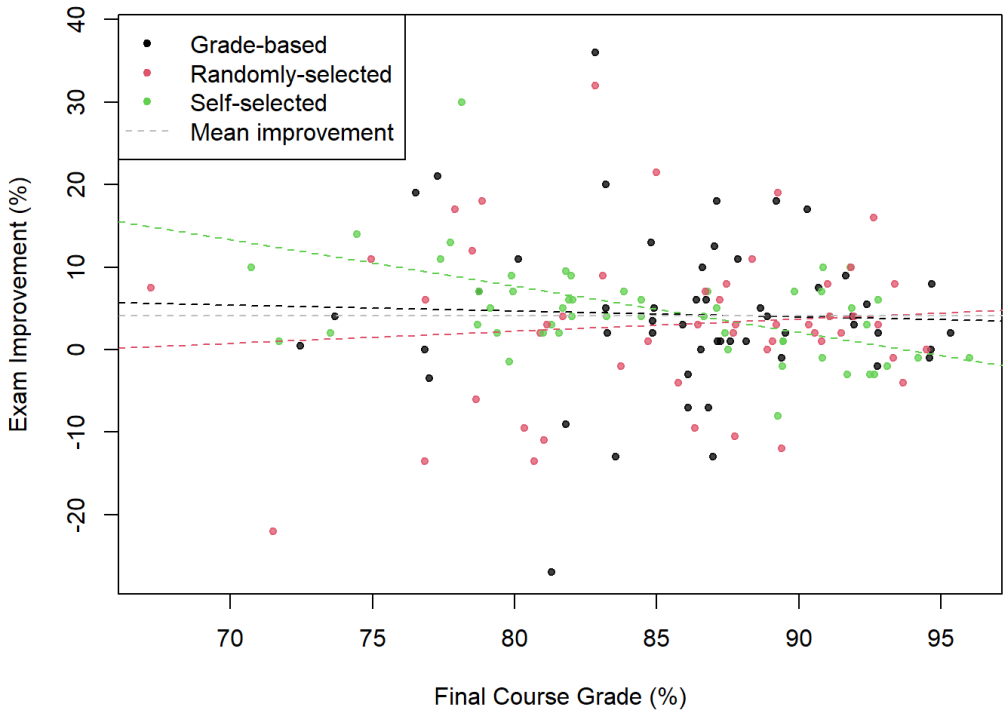

Figure 5. Exam improvement plotted as a function of final grade in the course. Linear least squares regression for the self-selected group was found to be statistically significant (p=0.0002). Mean exam improvement is shown for comparison.

4. Conclusions

Previous research suggests that processes to consistently produce optimal teams and assess student work in a perceived (by students) unbiased approach is elusive. This study contributes to the overall body of literature by examining courses within an environmental engineering curriculum to identify and analyze trends based on performance on team-based and individual graded events. At a program-level, the fraction of team points in overall course points ranged significantly from 0-80%. Courses without labs or large course projects tended to have a lower fraction of team points, whereas courses with labs and sizeable design projects, especially those tied to ABET EAC Student Outcome 5, had a much larger fraction of team points. Examination of point distributions in representative required major courses placed in the last four semesters of the environmental engineering curriculum concluded that team-based graded events did not equally benefit all students – lower performing students received a larger grade benefit than higher performing students. In some cases, higher performing students' overall grades suffered (i.e., decreased) due to group events. Further, it was concluded that group learning exercises did not significantly improve student learning for subsequently administered individual exams. Within one large enrollment course (EV450), we examined how teams were selected to determine if there was any impact on overall grades. Herein, we concluded that students allowed to select their own teams (i.e., self-select) earned grades that mirrored their overall course grade. However, teams where students were randomly assigned, or where students were purposefully grouped based on previous performance (i.e., lower performing students were placed with higher

performing students), lower performing students earned higher grades on the group assignment than other events in the course.

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