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Impact of Team Formation Approach on Teamwork Effectiveness and Performance in an Upper-Level Undergraduate Chemical Engineering Laboratory Course*

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This study focuses on the impact of team formation approach on teamwork effectiveness and performance spanning three years of instruction of the chemical engineering unit operations laboratory, which is an upper-level undergraduate laboratory course. Team formation approaches changed each year, and assessment tools, including peer-assessment, academic performance, and course evaluations, were employed to evaluate team performance. Approaches included three cases: instructor-selected teams based on GPA with the objective of a similar cumulative average GPA for each team, student self-selected teams, and a combination of self-selected teams with instructor-selected teams for a final experiment. For the third case, new teams were assigned based on a common interest to learn about a specific final laboratory experiment or research topic, and the instructor identification of both low- and high-performing students in the prior teams. Team effectiveness and performance were assessed using CATME, a teamwork VALUE rubric developed by the Association of American Colleges and Universities (AAC&U), and numerical peer-contribution forms. In addition, assigned team leaders for each experiment provided feedback regarding individual team member performance, including contributions to reports and presentations. Results demonstrated that less than five percent of the students presented team conflicts when students self-selected teams for the laboratory course; however, strong or weak teams were formed leading to unbalanced laboratory performance. On the contrary, course evaluation outcomes were improved when students were assigned to teams based on cumulative GPA or reassigned by the instructor for the completion of a final experiment. Overall, this study demonstrates that a combination of student-selected and instructor-selected teams during the same semester led to better course outcomes and enhanced individual experiences, as shown by the students' evaluations of the laboratory course.

Keywords: teamwork; laboratory; engineering laboratory courses; laboratory team assessment; team leader; team formation; unit operations laboratory

1. Introduction

Undergraduate engineering laboratory courses rely extensively on achieving teamwork development and hands-on learning through the completion of experiments. However, little to no guidance is typically given to the students regarding methods to work efficiently in a team or to instructors in assigning teams and promoting effective teamwork. In a traditional hands-on engineering teaching laboratory, students are encouraged to developing various technical and soft skills while working in a team [1]. The importance of undergraduate laboratories emerges from the need to provide students with the opportunity to apply engineering concepts learned in the classroom in mid- to large-scale operations, which typically demonstrate how real-world operability deviates from idealized text-book examples. These laboratories are frequently used as showcases for recruiting undergraduate students at universities [2]. Teamwork experience and an ability to be a good team member is a quality that many employers value and is an essential skill that needs efficient assessment at the undergraduate level [3, 4]. Unfortunately, the hands-on concept with complex systems of the unit operations laboratory experience to physical systems is a new concept for many students, which adds complexity to working efficiently as a team – a well-recognized problem in many academic levels [5–8]. Thus, the difficulty of achieving an effective level of teamwork performance in a laboratory is not only based on the encountered technical hands-on challenges, but also on the approach used for the team formation, each individual's technical knowledge and communication, and the desired learning goals of each student.

Few studies have focused on team performance and the ubiquitous challenges found in undergraduate engineering laboratory courses. In classroom settings, however, it is known that working in a team relies heavily on individual accountability, personal motivation, and a desire to succeed as an individual and as a team member [9]. Conflicts, poor commu-

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nication skills, "free riders", or personal differences are typical examples of problems encountered when students work in teams [10]. Gender and race inequalities also have a significant impact on teamwork performance, in particular for students in engineering majors [11, 12]. Additional concerns arise when forming teams for long-term projects, such as project-based learning (PBL) modules or senior design projects. Technical knowledge, cultural and personal differences, and the nature of the assigned project have all been identified as potential issues in the team forming process [13]. Also, interpersonal conflicts related to the unequal effort and contribution of the team members and poor time management affect team productivity [14]. The majority of these challenges are observed in upper-level engineering laboratory courses. Therefore, it is necessary to consider all of these aspects when forming teams and evaluating performance.

In many instances, the team formation approach can be correlated to low performance in team-based course work [15]. There are three recognized ways to form teams: student-selected teams, instructor-selected teams, and random selection (i.e., luck of the draw). Teams selected by the instructor, however, are the recognized team formation approach found in the literature; the primary intent is typically to avoid teams with only strong or weak students, or to assign teams based on pre-existing friendships [10, 16]. Many approaches can be used by instructors to form or assign teams, which can include teaming students by learning styles and personalities [17], academic performance based on GPA [18, 19], a peer-teaching environment (*e.g.*, the jigsaw method and latent jigsaw method) [20], or even by undisclosed instructor selection criteria [21]. Metacognition, critical and creative thinking, and enhanced learning are improved when teams are assigned by the instructor, and as a result, team assessment becomes critical to evaluate this type of learning enhancements [22].

A variety of assessment tools have become increasingly important to enhance teamwork experiences on class projects and assignments [23–25]. For example, coaching sessions and reflection of team-based work provides better learning outcomes and overall team satisfaction [26]. Communication, both at an informal and formal level, is a crucial component used to enhance teamwork effectiveness and innovation [27]. Peer assessment, which provides feedback regarding the students' individual performance perceived by the team members, and self-assessment are emerging tools used to evaluate teamwork performance at an individual and collaborative level [28]. Due to the active hands-on and applied learning experiences found in laboratory courses, implementing all of these approaches can lead to significant challenges while attempting to maintain the high-technical demands and expectations found in upper-level undergraduate technical courses and laboratories [29, 30].

Peer evaluations are useful tools to assess learning and actual skills achieved as long as these are designed adequately by identifying external factors – including evaluator strictness – that could lead to inconsistent evaluations [31]. Peer evaluations combined with anonymity leads to constructive feedback on teamwork performance when instructional context and goals are considered [32]. These types of evaluations are conducted either using computer-based or paper-based evaluations. Computer-based peer evaluations available online [e.g., the comprehensive assessment of team member effectiveness (CATME)] use a series of questions to assess the involvement and efficacy of individual performance on a team [28, 33]. Data is collected through an online questionnaire and is used to assess team performance by providing detailed feedback to the instructor and students. Challenges, however, have been reported in the literature when using CATME, including the low acceptance of students in using the web-based software [34]. Also, CATME, which is only available via web access, is not an open-access software, limiting its use at many Universities worldwide. Another non-open access software, SPARK^{PLUS} has recently garnered attention for self and peer assessment with feedback [35]. Alternative computer-based approaches for assessing teamwork have emerged; for example, assessment of individual performance within a team has been analyzed through learning analytics systems [36]. An additional approach includes the implementation of meta-heuristic algorithms to assess teamwork [37]. Recent literature still suggests CATME as the preferred online web-based tool utilized to assess teamwork in higher-level education [38].

In contrast to computer-based peer evaluations development, questionnaires, forms, or paper-based evaluations have simultaneously been developed as potential tools to assess peers' performance in teamwork efforts. These forms are usually freely available online. For example, one-page forms with a numerical peer evaluation assessment are provided by the Eberly Center at Carnegie Mellon University [39]. Other questionnaires, such as the learning partner rating scales (LPRS), present five questions related to meeting preparation, contribution to the discussion, attendance in lab and team meetings, promoting a positive learning environment, and effective communication [40]. Similar questions are provided in a teamwork VALUE rubric developed by the Association of American Colleges and Universities (AAC&U) [41]. Students can complete these forms more rapidly than online questionnaires, which could lead to higher survey completion yields.

To the authors' knowledge, there are many gaps in literature related to teamwork analysis in undergraduate engineering laboratory settings related to team formation and performance, instructor-selected versus self-selected teams, and the use of peer assessment tools. In this study, the impacts of team formation approach and the use of peer evaluations are analyzed for an upper-level chemical engineering laboratory, the unit operations laboratory, over a period of three years. The team selection approach for the three years was varied, and included: instructor-selected teams based on GPA, student self-selected teams, and a combination of self-selected and instructor-selected teams. Peer assessment tools, including CATME surveys, numerical peer evaluations from the Eberly center at Carnegie Mellon, and the teamwork VALUE rubric provided by the AAC&U, were used each year to provide additional insight regarding the observed team performance and effectiveness. Due to the rigorous academic requirements in this upper-level laboratory, it was not feasible to utilize the three team formation approaches within each semester. Therefore, insight and quantitative analysis regarding the impact of the team formation process on overall performance was achieved via comparison of final report grades and course evaluations

In this work, the methodology section highlights important aspects of the upper-level laboratory course, the grading schemes, the team formation approaches, and the implementation of peer-assessment tools and team evaluations for each year of assessment. The results and discussion section report the survey results for each team formation criteria and are presented as follows: case I (instructor-selected), case II (self-selected), and case III (combined team selection approach). A comparison of the final report grades and the course evaluations is then highlighted to determine the efficacy of the team formation approach in this upper-level chemical engineering laboratory course.

2. Methods: Laboratory, Grading Scheme, Participants, Team Formation, Peer-Assessment Tools and Team Evaluations

2.1 Laboratory

The unit operations chemical engineering upper-level laboratory integrates concepts of fluid flow, heat transfer, and separation processes [42, 43]. Also, other chemical engineering unit operations experiments (e.g., drying processes) allow the students to obtain hands-on experience of chemical engineering concepts and equipment utilization. This laboratory is designed to provide the students with an upper-level experience, commensurate with that expected upon completion of an undergraduate degree in engineering. The main objectives of this laboratory are: (1) to obtain a practical experience, (2) to prepare experimental plans, formulate hypothesis, and analyze data by comparing experimental results to applicable models and theory, (3) to work collaboratively in teams while complying with safety standards, and (4) to present results in written reports or technical presentations and offer peer review. Near the end of each term, the students can extend the design, creativity, and psychomotor capabilities developed during the semester by choosing a final experiment which provides the opportunity to select equipment and design their own experimental objectives. This final open-ended experiment helps to evaluate the technical and soft skills developed by the students while providing a means to extend their skill set beyond a simple data collection system and analysis.

2.2 Grading Scheme

Laboratory course grades have a large percentage assigned to team contribution (70% of the total grade), which includes contribution from a total of five reports. A traditional report consists of a joint team effort that summarizes a laboratory experiment performed during a period of two five-hour sessions. An increasing grading scale is assigned for each subsequent report, placing a higher value on improving technical and writing skills. Additional requirements are added to each subsequent report. For example, the first report accounts for only 5% of the grade and includes a simple calibration experiment and data analysis. The final experiment requires four five-hour sessions of data collection, and the report accounts for 20% of the total course grade. The final document must contain the traditional Introduction, Methods, Results, and Discussion (IMRAD) approach of a full technical report.

Individual performance comprises the remaining 30% of the grade. The instructors evaluate the technical skills of the students in a one-on-one team leader meeting for every report, and a rubric has been developed to assist in the evaluation. The rubric evaluates technical and presentation skills, including organization, technical content, presentation style, and team leadership skills [43–45]. It is required that each student serves as the team leader for at least one experiment completed during the semester. The instructors pose technical questions to the team leader of each experiment to evaluate their understanding of the presented work. Additionally, soft skills are evaluated in technical presentations including communication with team members and team leadership skills. It is critical to perform experiments in a safe environment, and safety is assessed at an individual level using various forms, quizzes, and instructor observation.

2.3 Participants

Each semester, four laboratory course sections are offered, with each section containing a minimum of 15 and a maximum of 24 students. Traditionally, each section consists of five or six teams of three to four students. Students enrolled in this course are senior-level and have completed prerequisite courses in the core chemical engineering curriculum. The laboratory course is offered once a year to senior students only, who at the end of the academic calendar year graduate with a Bachelor of Science degree in chemical engineering. Because this study was performed in three years – each year represented by a case number – the student population for each team formation approach was not constant. The specific student population and the number of teams assessed for each team formation study are presented in Table 1. The same three instructors taught the four sections of the laboratory for each team formation case. Each year, one instructor taught two laboratory sections.

2.4 Team Formation

The impact of the approach used for team formation on this upper-level chemical engineering laboratory was analyzed for three years, and an overall scheme of the three individual case studies is shown in Fig. 1. As discussed in the introduction, three different team formation approaches were utilized, and each approach was implemented and assessed during each year of the study.

2.4.1 Case I

Students were placed in teams selected by the instructors based on individual grade point average (GPA). Teams were assigned based on academic performance in engineering classes (engineering GPA) since this was believed to be most pertinent to expected laboratory performance. Team selection by instructor guaranteed that at least a strong student (high engineering GPA) was in each team; in addition, the cumulative GPA for each team were similar.

2.4.2 Case II

During the second year of this study, students were allowed to select their own teams without instructor involvement. This approach yielded consistent team formation found in the literature and described in the introduction. Teams of high and low academic performance were formed and their performance in the laboratory was assessed.

2.4.3 Case III

For the third year, students were allowed to select their own team for completion of the standard set of four experiments and reports; however, teams were reassigned by each instructor for the final extended study based on student preference for a specific laboratory experience or research topic (e.g., fermentation analysis or heat exchanger design) and instructors' observations on individual performance earlier in the semester (Fig. 1).

2.5 Peer-assessment Tools, Grades and Course Evaluations

2.5.1 Case I

The Comprehensive Assessment of Team Member Effectiveness (CATME) was used to analyze team performance and effectiveness during the first year. CATME assessment was requested to be completed

Table 1. Total number of students and teams participating in the laboratory for each team formation approach

	Case I	Case II	Case III
Number of laboratory sections	4	4	4
Total number of students for all sections	93	62	85
Number of teams per section	6	5*	6
Number of students per team	3–4	2–3**	3–4

* One section had six teams. ** For this particular case, in the section of six teams one team of two students was formed.

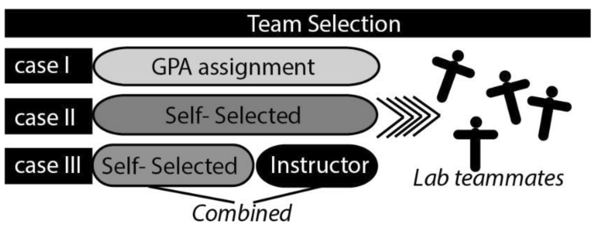

Fig. 1. Team formation studies analyzed each year for an upper-level chemical engineering laboratory instruction.

by the students prior to the end of the semester evaluating an entire semester rather than an individual report. An additional numerical peer assessment form, obtained from the Eberly Center at Carnegie Mellon University, was completed by the team leader of each experiment and provided to the instructor after a one-on-one debrief presentation [39]. The numerical form required a team leader self-rating and ratings for the additional team members.

2.5.2 *Case II*

Peer-evaluation surveys for team assessment were administered using a Google form with the same questions found in the teamwork VALUE rubric listed by the AAC&U [41]. The numerical peer-assessment form was provided by the team, and it was attached at the end of each report after approval of all team members. For this case, all numerical evaluations were required by the instructor to reports two to four.

2.5.3 *Case III*

The same assessment tools as outlined in case II were used. However, these peer-evaluations were only considered for the final experiment and report (Section 2.1).

2.5.4 *Grades and Course Evaluations*

Additional analysis is performed by examining final report grades (the highest contributor to the laboratory grade; section 2.1) because teams were changed on the third year specifically at this point in the semester (Fig. 1). Thus, a comparison of the three case studies on team formation approaches is analyzed through students' final report grades. To understand the impacts of team formation approach, results on specific student course evaluations questions were assessed, including: (1) This course stimulated my interest in the subject, (2) This course increased my understanding of the subject, (3) I learned a great deal from this course, and (4) I would recommend this course to other students. Responses were collected using a 5-point scale, where 1 = strongly disagree and 5 = strongly agree.

3. Results and Discussion

3.1 *Case I: Instructor-Selected Teams Based on the Students' Engineering GPA*

Each team with four students included one high-GPA student, two average-GPA students, and one low-GPA student. Throughout the semester, CATME was used to assess student performance and a numerical peer-evaluation form completed by the respective team leader of each experiment after an individual presentation provided only to the instructor. The student leader was responsible for distributing work equally among all members of the team and assigning deadlines for each laboratory task. During the one-on-one presentation with the instructor, the team leader was asked to provide details on the contributions of each team member while conducting the experiment and compiling the submitted report. This data was collected by the instructor to identify unequal workload distributions among members of a team. The numerical evaluation provided by each team leader was not released to the other members of the team to avoid potential conflicts or issues in subsequent experiments required in the laboratory.

For this case, the team leader completed a numerical evaluation form to assess each team member performance, including a leader self-evaluation, for each report [39]. The numerical evaluations were provided to each team leader for reports two to four, and the completion of the form was not mandatory. Thus, from a total of 24 teams – six teams in each section – a completion rate of 47.2% is reported (34 reports out of 72). The results from these evaluations showed that $\sim$ 27% of the teams had equal contributions from all members, 33% of teams had most of the contributions from two students, and in the remaining 40%, one member was leading and completing all the work individually. From the results obtained, the student – or the two students – who led the work individually were typically the high GPA students. Qualitative observations of the high performing students included: lack of trust in technical knowledge of the low GPA students, "know-it-all" mentality, fear of earning a bad grade due to inadequate team members' calculations, and lack of motivation to work with other students for the first time. It is important to note that some teams worked well and did not have any collaborative issues. In fact, comments from the students revealed that working on a team for an entire semester improved cohesiveness as the semester progressed.

CATME evaluations were completed individually at a 99% rate (92/93 students completed CATME). The evaluations were made mandatory by the instructors in an effort to assess the entire semester of team performance in the laboratory. The results presented in this study are limited to the Likert Short Version of CATME [33]. Specific parameters evaluated and assessed are listed in Table 2. Response rates were recorded on a 5-point scale, where 1 = strongly disagree, and 5 = strongly agree. The standard deviations reported in Table 2 indicate the degree of variability on the team performance. From the CATME evaluation, 10 students were characterized as high-performers by their team members. The students with this characteristic were the high-GPA students, and this information correlates with the results of previous studies on which students with high GPA are more concerned for their grades as compared to under-performing students [46–48]. Five students were identified as under-confident, meaning that the rating of the peers was higher than their individual rating. Results indicated that the average GPA students lie in this category. On the contrary, five students had an over-confidence rating, indicating that their own perceived contribution to the team's effort was higher than the cumulative contribution reported by the team members. The over-confidence result correlates with the lowest GPA students. According to CATME results, 9 out of 24 teams (37.5%) did not have any conflicts or issues when evaluating team performance. This result is very comparable to the one reported in the numerical evaluations, but CATME was completed only at the end of the semester, and the students complained about the ambiguity of the survey and the time it took for completion. Also, CATME is no longer open-access software and could lead to obstacles when setting up annual surveys. For these reasons, the instructors opted to use two peer-evaluation assessment tools to analyze the following team formation cases of study.

3.2 Case II: Student Self-Selected Teams

Similar to CATME, the AAC&U teamwork VALUE rubric evaluates the parameters listed in Table 3, but on a 4-point scale. For this particular rubric, 1 indicates a benchmark experience (negative) and 4 indicates a capstone experience (positive). Contrary to CATME evaluations, this rubric provides specific details and definitions for each assessed category such as the explanation on assigning a capstone, milestone, or benchmark mark to a member of the team (the reader is referred to check the definitions listed on the rubric which is available online) [41]. The completion of the teamwork rubrics was required for reports two to four for all the student members on each team. Therefore, data is shown for teammate 1 and teammate 2, where the evaluator is the third team member in a team of three students (Table 1). Note that the rater – the member completing the form – was not evaluated or included in the evaluation assessment. Overall, results showed that less than 5% of students reported a negative experience when the teams were self-selected (1-point assigned to a benchmark category in the survey), and most of the evaluation were closed to the maximum 4-point value as shown in Table 3. This data is confirmed by the second assessment tool used for this case, the numerical peer-evaluation forms which were requested by the instructor to be included with each report submission. Result showed that only 10% of the teams reported slightly different member contributions throughout the semester on the completion of the reports. In summary, case II resulted in a few reported cases of low performing teams in each laboratory section, fewer comments of team performance, and less student willingness to participate in the peer-evaluation surveys. The latter occurrences are likely attributable to students' team selection based on pre-existing interpersonal relationships

Table 2. CATME results for instructor assigned teams based on Engineering GPA (case 1)*

	Mean	SD
Contributing to the team's work	3.84	1.03
Interacting with teammates	3.91	0.88
Keeping the team on track	3.83	1.04
Expecting quality	3.86	0.89
Having relevant Knowledge, Skills, and Abilities	4	0.97

N = 92. * Ratings are assigned on a 5-point scale, where 1 indicates strongly disagree and 5 indicates strongly agree.

Table 3. AAC&U Team evaluation results for self-selected teams (case II)*

	Teammate 1		Teammate 2	
	Mean	SD	Mean	SD
Contributes to Team Meeting	3.84	0.47	3.71	0.65
Facilitates the contribution of team members	3.66	0.62	3.57	0.82
Individual contributions outside of Team meetings	3.70	0.62	3.61	0.73
Foster constructive team climate	3.76	0.56	3.76	0.66
Responds to conflict	3.76	0.52	3.69	0.74

N = 50. * Rankings are assigned on a 4-point scale, where 1 indicates a benchmark experience and 4 indicates a capstone experience. A complete explanation on each point assignment can be found in the AAC&U teamwork VALUE rubric [22].

Table 4. AAC&U survey results for instructor-selected teams for the final experiment based on students' topic selection and previous individual laboratory performance (case III)*

	Teammate 1		Teammate 2		Teammate 3	
	Mean	SD	Mean	SD	Mean	SD
Contributes to Team Meeting	3.63	0.76	3.6	0.73	3.61	0.74
Facilitates the contribution of team members	3.36	0.93	3.52	0.83	3.36	0.96
Individual contributions outside of Team meetings	3.39	0.95	3.45	0.97	3.51	0.92
Foster constructive team climate	3.61	0.81	3.61	0.84	3.49	0.86
Responds to conflict	3.59	0.73	3.59	0.84	3.59	0.85
	N = 83		N = 83		N = 59	

* Rankings are assigned on a 4-point scale, where 1 indicates a benchmark experience and 4 indicates a capstone experience. A complete explanation on each point assignment can be found in the AAC&U teamwork VALUE rubric [22].

and work experience (i.e., select team members with similar work ethic and academic success), and students less likely openly critique their colleague's performance [4].

3.3 *Case III: Combined Team Selection Including Student Self-Selected and Instructor-Selected Teams*

A new team formation approach was introduced with the goal of validating the two previous cases of study, and identify improvement on learning outcomes. During the first four experiments, students were allowed to work in self-selected teams, and confidential survey completion was not mandatory but suggested if team conflict was present (as suggested by the students' evaluations of teaching when self-selected teams were made in case II). Only 10% of the teams in each section completed the survey for the first four experiments, and most of these surveys were related to lack of technical capabilities of one team member. This individual(s) was usually the left-out student, which is a result comparable to the previous cases presented in this work. In fact, these results confirm the Oakley et al. study that instructors should form the teams rather than allowing a self-selection process [10]. Here, the authors validate and confirm this event for an upper–level Engineering laboratory course. To test team performance and effectiveness during the same semester and with the same subset of students, a new approach was undertaken where the instructor assigned teams for the final experiment, which accounted for 20% of the overall laboratory grade. Each student in each section was given a list of six research topics and was asked to rank the topics in order of individual interest. Instructor selection was performed knowing the GPA, work ethic and interpersonal skills of each student in the laboratory, while considering the top three topic choices from each student, with the intention of forming cohesive teams with equitable workload distribution.

Once teams were assigned by the instructors for the final experiment, all expectations were presented to the teams at the beginning of the final experiment session. As compared to case I and case II, results for case III showed that most of the teams did not present the typical conflicts or issues observed in this final experiment in previous semesters, leading to fewer team conflicts or frustrations and better educational experiences when teams were reassigned. AAC&U survey results showed consistent data for all team members (Table 4). A total of 98% of the students (83/85; Table 1) completed these evaluations. On average, lower scores were provided to members of instructor-selected teams as compared to students self-selected teams (case II). Qualitative comments were also provided by the students and many complaints were still present from the underperforming students who were previously identified by the instructors at the beginning of the semester when teams were self-selected. Due to the short timeline after instructor team-assignments, some teams were incapable to demonstrate sufficient motivation to work cohesively and poor-quality final reports were submitted affecting students overall final grades. Despite this challenge, the assignment of teams by the instructor could lead to potential better individual experiences and students' course evaluations were used to confirm this hypothesis as discussed in the following section.

3.4 *Team Formation Approaches Impacted Final Report Grades and Course Outcomes*

An assessment tool that is consistent throughout the three cases of study is the final report evaluation. From the three cases evaluated in this study, case III had the lowest student final report grades, as shown in Fig. 2. Results showed that there were not significant differences in the grade achieved on the final report when the teams were self-selected (case II) and when the teams were assigned based on GPA (case I). This result, however, could be due to the

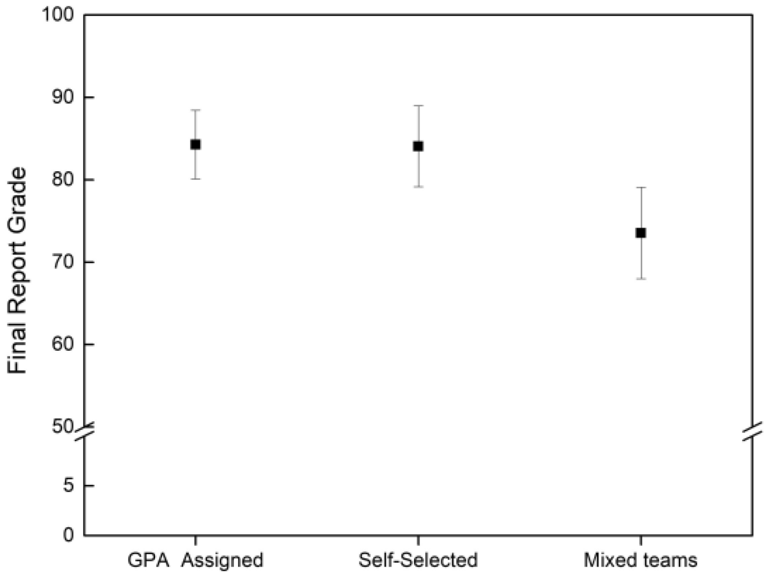

Fig. 2. Comparison of final report grades (20% of the total grade) in an upper-level chemical engineering laboratory course for three cases of student team formation analyzed throughout three-years. Error bars indicate a 95% confidence interval.

unavoidable year-to-year variability in class capability and individual student performance – a parameter that could not be controlled in this study. Nonetheless, to the authors' knowledge, this is the first time that such comparison is shown in an upper-level engineering laboratory course. Variations of final report grades could be attributed to a lack of time to develop cohesion for a new team with different students. The relationship between time and team development is a question that is yet to be answered and might depend on class-type, students, and requested deliverables [49].

In an effort to assess the impact of team formation approach in course outcomes, specific questions related to the course obtained through the student evaluations of teaching (SET) were assessed. SET is graded on a 5-point scale where 5 = strongly agree, and 1 = strongly disagree. The specific questions and

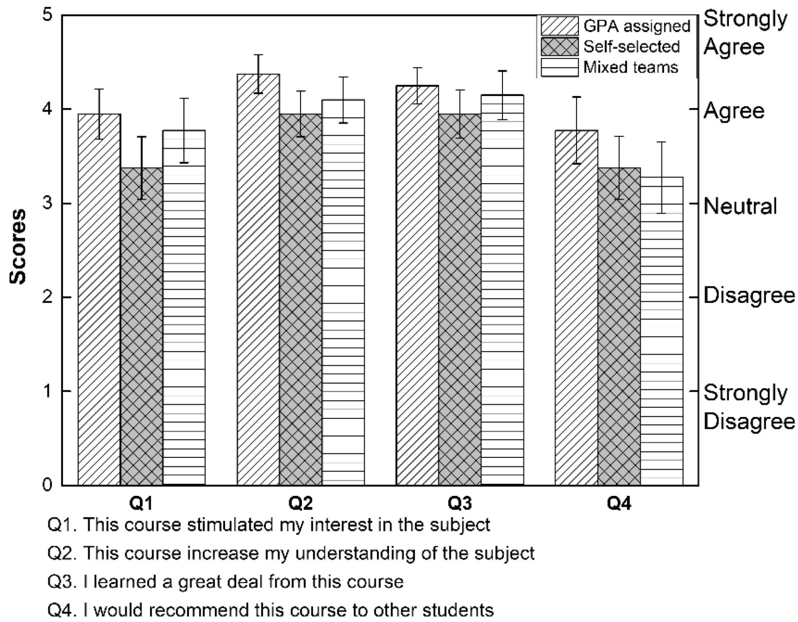

Fig. 3. Effects of team formation mechanisms on course outcomes included the analysis of instructor-selected teams based on GPA, students' self-selected teams, and a combination of self-selected and instructor-selected teams (mixed teams). Data compare results for three years of analysis. Error bars indicate a 95% confidence interval.

average results for the four laboratory sections taught each year for each case of study are presented in Fig. 3.

For case I, when the teams were assigned by GPA, a slightly higher evaluation was observed for all four questions. When the students selected their own teams (case II), it was expected that course evaluation would be high [50], but on the contrary, course evaluation scores were consistently low (Q1 and Q2, Fig. 3). Moreover, based on the course evaluations, results suggest that students evaluated in case I and case III had a slightly better learning experience during the course (Q3, Fig. 3) as compared to students in case II – the self-selected teams. When the teams were re-assigned by the instructor at the end of the term for the final experiment (case III), students seemed to be more apprehensive about recommending the course to other students (Q4; Fig. 3). This result could be due to the added stress of changing teams, adjusting to a new team dynamic, and the many demands that are experienced by the end of the first semester of senior year.

4. Conclusions

The impact of team formation approach on overall performance in an upper-level chemical engineering undergraduate laboratory course was assessed over a three year period. Team formation mechanisms were changed each year, including (case I) instructor-selected teams with the objective of achieving a similar cumulative average GPA for each team, (case II) self-selected teams by the students, and (case III) a combination of self-selected and instructor-selected teams. It is recognized that the variability of student academic levels may impact the analysis over this three-year study. Assessment tools for peer-evaluation – including CATME, numerical peer-evaluation forms, and the teamwork VALUE rubric from the AAC&U – were utilized to provide insight into team effectiveness and performance. The use of these peer-assessment tools deemed instrumental to better identify low- and high-performing students in an upper-level undergraduate chemical engineering laboratory setting.

Instructor-selected teams based on achieving a similar cumulative GPA and equitable workload distribution for each team provided better course outcomes related to interest and understanding of the subject in the laboratory course. By reassigning student teams on the final experiment, instructors noted improved team cohesion and less conflict throughout the semester as compared to instructor-selected teams for the entire semester. This case allowed the instructors to identify underperforming individual students in the laboratory before changing to instructor-selected team selection; thus, a balance during team reassignment was maintained. In some instances, team transition helped underperforming students to become assets in new teams, improving educational outcomes. However, in some cases, underperforming students were not capable of functioning at a higher level with a new team dynamic, leading to continued low performance. Despite a lower average score on the final report grade, the authors conclude that a combination of student-selected and instructor-selected teams led to better course outcomes and enhanced individual experiences, as shown by the students' evaluations of the upper-level chemical engineering laboratory. The results from this study could be applied to team formation approaches in other upper-level undergraduate engineering laboratories.

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