Effective Teamwork Dynamics in a Unit Operations Laboratory Course

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1. Introduction

The Chemical Engineering Unit Operations Laboratory is a unique course that relies heavily on a cooperative team effort for successful learning that leads to a compelling laboratory experience[1-3]. In this course, team assignments play a critical role in the performance of a group because every laboratory session involves peer interactions, hands-on experimentation from start to finish, data analysis and discussion, and a significant amount of writing time, *i.e.*, a workload that is intentionally more than one individual is expected to manage. The daunting workload for this course should involve an equal workload distribution, established deadlines, organized meetings, set literature reviews, and a thorough discussion of the experiments. All of these aspects encompass the definition of teamwork, which inherently promotes group responsibilities and individual accountability. Therefore, team formation is a vital component of the Unit Operations Laboratory.

According to Oakley et al.[4], for team assignments in a college classroom, groups should be made by the instructor rather than the self-selection left to the students. The Unit Operations Laboratory course is usually taught during senior years of the curricula, which means that most of the students know their peers and have established compatibilities with specific individuals to work in a preferred team. Here, it is recognized that team self-selection leads to at least one group struggling throughout the semester; but, for this course assigning groups has had a detrimental effect on the top students' performance and a negligent effect on weak students. In fact, at The University of Dayton, the team selection process varies on different courses. Some courses have assigned teams, and others are chosen by the luck of the draw, or self-assigned.

In addition to team assignment, social skills are another core component that must be fit to this class[5]. Without these skills, incompatible groups with poor communication are destined to fail in the delivery of reports and presentations. As recognized by ABET, current student outcomes (SO) from an academic program must prepare their graduates with "an ability to communicate effectively" (SO k), and the "ability to design and conduct experiments, as well as to analyze and interpret data" (SO b), and others [6]. In fact, the new ABET student outcomes, effective in 2019-2020, have a stronger emphasis on team efforts: "An ability to function effectively as a member or leader of a team that establishes goals, plans tasks, meets deadlines, and creates a collaborative and inclusive environment" (SO "3")[6]. All these outcomes can be assessed through the Unit Operations Laboratory; however, the main challenge is to implement practical tools for a team, either assigned or self-selected, to function properly throughout the semester. For instance, John D. Rockefeller's quote, "*I will pay more for the ability to deal with people than any other ability under the sun,*" describes well instructors' observations year after year of teaching the Unit Operations Laboratories either assigning teams or teams selected by students.

The main goal of this work is to assess individual student contributions and the performance of the group members by using open and confidential surveys. For each laboratory experiment on the core unit operations, a team leader is chosen by each group. The leader is responsible for assigning work to the other students and coordinating the responsibilities of each team member. After submitting a report, each team leader provides a one-on-one presentation with the

instructor, which results in an individual assessment during the semester. The team lead grades are assigned based on a rubric that identifies the organization, technical content, presentation style, and team leadership skills.

Additional assessment tools used in the course for grading reports, presentations, team lead briefs, and safety discussions are also discussed, and a general overview of the Unit Operations Laboratory is provided. This paper is organized as follows: (1) Description of the Unit Operations Laboratory and grading rubrics, (2) Methods for teamwork and individual assessments, (3) Results and survey discussions, (4) Suggested techniques for future works and (5) Conclusions from the study.

2. Description of the Unit Operations Laboratory

The primary objective of the class lies in practical experience, or experiential learning, by experimenting and troubleshooting chemical processing equipment in a collaborative environment. Through the Unit Operations Laboratory, the students are expected to:

- Define their own experimental objective
- Work in a team
- Conduct a literature review
- Observe safety standards
- Calibrate instrumentation
- Collect data and compare it to models and theory when applicable
- Present results, offer/receive peer review, and write engineering reports

During a semester, students are placed in groups of three or four depending on the number of enrolled students. Each laboratory section has six groups or seven groups at a maximum due to equipment and space availability. Overall, a total of six experiments are performed: a calibration experiment, three core unit operations experiments (focusing on heat transfer, fluid flow, and separation process), an operability study, and a final project. A full detail calendar for the term is shown in Table 1. The calibration experiment is the first required report, and it is focused on verifying the existing instrumentation or recommend a calibration for a piece of equipment such as a rotameter or pump. For the three core experiments, the students have two weeks of experimentation and one additional week to write a report. The operability study is performed during one week of experimentation, and the students make a presentation or write a two-page memo to summarize their findings during the following week. The presentation or the memo seems to be beneficial for the students' learning as this experiment is conducted in the middle point of the semester, which allows the students to re-orient themselves and analyze their group and individual performance. Lastly, a final experiment that is designed by the students is run for four to five weeks. Note that each laboratory section meets once a week for five hours each session. This weekly session is strictly dedicated to experimentation. Overall, the students know that this laboratory is a very demanding course on which they need to make maximum use of their time and resources to deliver high-quality reports.

Table 1. Unit Operations Laboratory class schedule during a Fall Semester

Timeline	Experiment type	Deliverable
Week 1	Calibration	Data Analysis
Weeks 2 - 3	Fluid Flow	Report
Weeks 4 - 5	Heat Transfer	Report
Week 6	Operability	Presentation or Memo
Weeks 6 -7	Separations	Report
Weeks 8 - 12	Final Project	Full Report

For each semester, four sections with approximately 15 – 18 students are assigned. A variety of experiments are available for each group, and the order of the core experiments: fluid flow, heat transfer, and separation processes can change based on equipment availability. Table 2 shows a summary of the different experiments that are run throughout the semester. For example, Team 1 will run the manifold and fitting pressure drop analysis as part of the fluid flow experiment, the bubble cap distillation column for a separation processes experiment, and a shell and tube heat exchanger for heat transfer analysis. Figure 1 shows examples of equipment available for the three core experiments in the unit operations laboratory run by Team 1. Before allowing any group to initiate an experiment in the Laboratory, a request to experiment form must be completed (Appendix 1), and a 15-minute discussion between each team, the lab manager, and the instructor proceeds. The assigned team leader for the specific experiment is required to represent the team (*e.g.*, discuss objectives, answer technical questions, review safety, and others) during this discussion.

Figure 1. A) Manifold and fitting pressure drop experiment, B) shell and tube heat exchanger, and C) bubble cap distillation column.

Grading

Grades are assigned based on individual and group evaluations as shown in Table 3. The group contribution accounts for 70% of the grade and is based on reports. There is a strong emphasis on uncertainty, calculations, data analysis, and conclusions for each report. For the fourth and fifth (final) report, additional components are included such as: introduction, literature review, apparatus description, procedure, and safety review. The grades for the initial report have a lower percentage contribution to the total grade whereas the final experiment, which is run for four

weeks, accounts for 20% of the total grade. Report grades and specific components required for each report are given to the students based on the rubric shown in Appendix 2. For this class, the laboratory is run strictly by the instructor and the laboratory manager. All grades are assigned only by the instructor of each section; however, a session between all the instructors is held at the end of the semester to discuss the performance of each section and attempt to correlate overall grades between sections.

Table 2. Experiment schedule for the Unit Operations Laboratory

Team	Reports1 & 2	Report 3	Operability	Report 4
1	manifold & fitting pressure drop	bubble cap distillation	reverse osmosis	shell & tube heat exchanger
2	shell & tube heat exchanger	centrifugal pump	filter press	bubble cap distillation
3	packed distillation	shell & tube heat exchanger	vacuum dryer	manifold & fitting pressure drop
4	Yamato Spray Dryer – 1 Agitation - 2	gas absorption column	Yamato spray dryer	plate & frame heat exchanger
5	plate & frame heat exchanger	manifold & fitting pressure drop	injection molder	gas absorption column
6	gas absorption column	plate & frame heat exchanger	Swenson spray dryer	centrifugal pump
7*	concentric tube heat exchanger	agitation	fuel cell	packed distillation

* with permission of the instructor

Table 3. Grading distributions for the Unit Operations Laboratory

Individual Contribution	
Individual performance & Team Lead responsibilities	10%
Presentation: Final and Operability	10%
Safety: performance in the laboratory and quizzes	5%
Individual Quizzes	5%
Individual Sub-Total	*30%*
Group Contribution	
Report #1	5%
Operability Presentation or Memo	5%
Reports #2 – 4	40%
Final Report	20%
Group Sub-Total	*70%*

The individual contribution accounts for 30% of the grade, and this includes the evaluation of soft skills, such as team lead responsibilities and the evaluation of the students' presentation

skills. Safety, individual performance, and individual quizzes are evaluated throughout the semester. The grading scale used for assessing the individual contributions is shown in Table 3. Challenges exist to evaluate individual contributions to a report and assign grades to a presentation. *Overall, assessment of group performance and individual team leader duties are the parameters of study for this work*. Results for instructor assigned team and students' self-selected groups are discussed. A description of the methods used in this class and the evaluation tools for assessment of teamwork are discussed in the next section.

3. Methods for Teamwork and Individual Assessments

The methods and analysis performed in this study were introduced in two separate semesters: Fall 2016 and Fall 2017. During the Fall 2016 semester, groups of four students were assigned and in the Fall 2017 semester students-selected groups were analyzed. In the Fall 2016 semester, it is important to note that the teams were not selected randomly, but rather, these selections were based on academic performance of each student. The groups, comprised of four students, were assigned while attempting to attain the same overall average grade point average (GPA) for each team. This selection was essentially accomplished by including individuals with a 'high' and 'low' GPA in each group.

Teamwork assessment was done on reports 2 – 4, which represents 40% of the total grade (Table 3). Each group assigned a team leader for each experiment and report. The team leader is responsible for assigning members with an appropriate workload distribution, must define deadlines, and discuss experimental objectives and the experimental plan. Also, it is encouraged that the students rotate duties, e.g., research, experimentation, and data analysis during the semester. For example, the team should allow more than one student to work in the data analysis and discussion section of a report, as this is one of the most significant contributors to the grade (Appendix 2). The team leader is also responsible for proofreading the report and taking an active role in planning and setting goals for the team.

Within the team leader responsibilities, a one-on-one discussion with the instructor using five to six slides must be provided at the end of each experiment. In this briefing, the leader should be able to summarize the entire project and include highlights and key points that were learned from the hands-on research and the report writing experience. Specifically, students are asked to provide five slides with an objective, experimental design and approach, theoretical model utilized for analysis, summary of the major outcomes, and conclusion and recommendations for future experimenters. Teamwork and personal interactions are also discussed in this briefing.

Table 4 shows the assessment tool that is used to evaluate the team leaders for each experiment. Four critical aspects are evaluated including organization, presentation style, technical content and team leadership skills. Since there are multiple sections taught during the same semester by different instructors, different numerical values have been given to each parameter. For example, technical content has a value of 50 points but assigning full credit to the student (4 points) will result in a total of 200 points for the technical content evaluation only. In total, the maximum points allowed for a student, which will include 4 points assigned in all categories, will be 460 points. The rubric developed by the instructors to assign different values is shown in Appendix 4. Current evaluation of the form and the implementation in the course are discussed in the next section.

Table 4. Rubric to evaluate team lead efforts during the semester

Team lead Presentation Evaluation CME466L Section___ Group # _____ Experiment: _____ Student: _____ Date: _____				
	4	3	2	1
Organization 15 pts				
Technical Content 50 pts				
Presentation style 30 pts				
Team lead skills 20 pts				
Additional Comments:				

Assessment of individual work is provided by the students using an open group assessment form, which is attached at the end of each report (Appendix 3.1). This document provides an opportunity to self-assess the internal communication, division of labor, and roles in the group. The team leader is responsible for drafting the team assessment and reviewing with the team. Each team member acknowledges the compiled information via signature, and the team leader revises it before submitting the report to the instructor. This form adds individual accountability to the report and has also been used to identify internal conflicts within a group as the team leaders can report these incidents directly to the instructor. Results from assessments, both confidential and signed by each student, will be discussed in the next section [A copy of the team lead form is provided in Appendix 3.1].

In addition to the group assessment form for team evaluation, this study implements confidential surveys through google forms that are based on the teamwork value rubric provided by the Association of American Colleges & Universities (AAC&U; Appendix 3.2) [7], and numerical peer assessments from the group members which are based on the Eberly Center resources for group projects and it is available online [8]. To the authors' knowledge, this is the first time that these rubrics are used in assessing teamwork performance in a unit operations laboratory. The full rubric for assessing the team members was provided to the students, which is also accessible online [7] and reprinted in Appendix 3.2. The survey was not graded or required for the course, but the students were more than willing to participate to communicate any differences between

members in a group. The confidential surveys have been administered on two separate semesters, once when the groups were made by the instructor in the Fall 2016 term and the second time when the groups were self-selected in the Fall 2017 semester. In 2016, the numerical peer evaluations were completed only by the team leaders when groups were assigned. However, in 2017, the AAC&U confidential survey and the group assessment form were completed by everyone in the group. During both years, the results were kept confidential. However, the instructors intervened as necessary when significant differences and problems were observed. The discussion on these results is presented in the next section.

4. Results and Survey Discussion

First, the results of the numerical peer evaluations are presented when the instructor assigned teams. As each team leader led a presentation, several disagreements and conflicts within the groups were shared with the instructors, and these results were reflected in the numerical peer evaluation. Figure 2 shows the results of the numerical surveys provided to the students during the Fall 2016 semester when teams were assigned based on individual academic performance. From the results, it is observed that only 27% of the groups have members that contributed equally to the amount of work distributed in the laboratory and during report writing.

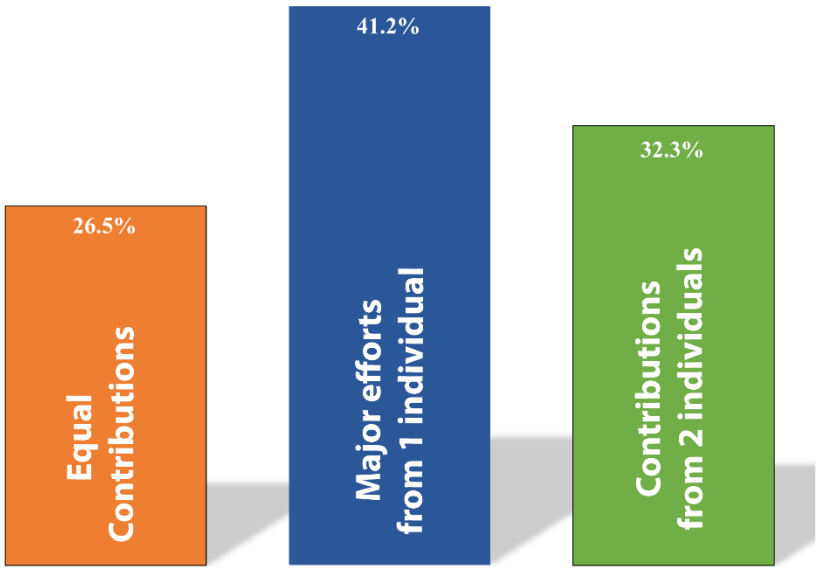

Figure 2. Results of confidential numerical peer assessment surveys administered to team leaders after team debriefs when the instructors assigned teams of four students during the Fall 2016 semester [Results are based on a total number of 34 surveys and groups of four students]

Interestingly, results show that 41% of the time, one member of the group was completing most of the assigned load while working in the reports and in the laboratory, with the rest of the group being a “free-rider”. Another interesting factor that was present in this semester is that two individuals can also lead the group. This factor happened ~ 33% of the time. In fact, through the individual survey, it is observed that the underperforming students recognized the individual(s) completing most of the work for the group; however, no efforts were made to improve their performance. Despite multiple discussions within the team, and even the instructor, these results

did not improve as the semester progressed. Thus, it is inferred that some members did not seem proactive or motivated even though their efforts were not enough for the team success. Despite this negative outcome, the instructor and the students knew about the uncomfortable situation within the group, leading to open work experiences in the laboratory.

A second approach was utilized in the Fall 2017 semester, and the instructors allowed self-selection of the teams and the participation of every team member in evaluating the performance of the group. During the Fall 2017 semester, with groups of three students, the AAC&U teamwork value rubric[7] and the team leader assessment form (both shown in Appendix 3) were used to observe and predict teamwork dynamics. The AAC&U focuses on five specific questions:

- Contribution to team meetings
- Facilitates the contributions of team members
- Individual contributions outside of team meetings
- Fosters constructive team climate
- Responds to conflict

As shown in Appendix 3, the rubric uses a scale from 4 to 1, on which 4 represents a capstone experience (positive) and 1 a benchmark performance (negative). Students had complete access to the rubric prior to filling out the Google form with the five questions listed earlier and understood the values of their answers. In a group of three students, one student evaluated both peers with the AAC&U rubric. Results for the evaluation of reports 2 – 4 is shown Appendix 5 , Appendix 6, and Figure 4 respectively. Each plot represents the evaluation of one member of the group to their peers. For example, in a group of three students (A, B, and C). Student A evaluated student B (Fig. A) and student C (Fig. B) with the five questions of the rubric for each report evaluated.

Results for the evaluation of Report 4 had the highest response rate from students (61/63) and are shown in Figure 3. The results for reports 2 and 3 are shown in Appendix 5 and 6, respectively. To the instructors' surprise, less than 5% of the students had a benchmark, or negative experience, when the teams were self-selected. Capstone and milestones were mostly observed throughout the reports (Fig. 3, App. 5-6) as confirmed by assigning values between 4 and 2 to the specific questions of the survey. The instructors believe that by report 4, the groups have identified their weaknesses and strengths. In fact, more report sections are required for report 4, as shown in the grading rubric, resulting in a higher workload distribution. Despite these constraints, results are positive with at least 70% of the students achieving a capstone experience for all the questions (a response of 4) while working in groups that were self-selected in the unit operations laboratory. Note, however, that this rubric does not capture specific individual technical contributions to the report. *For this reason, the team lead assessment form was also used as a second approach.*

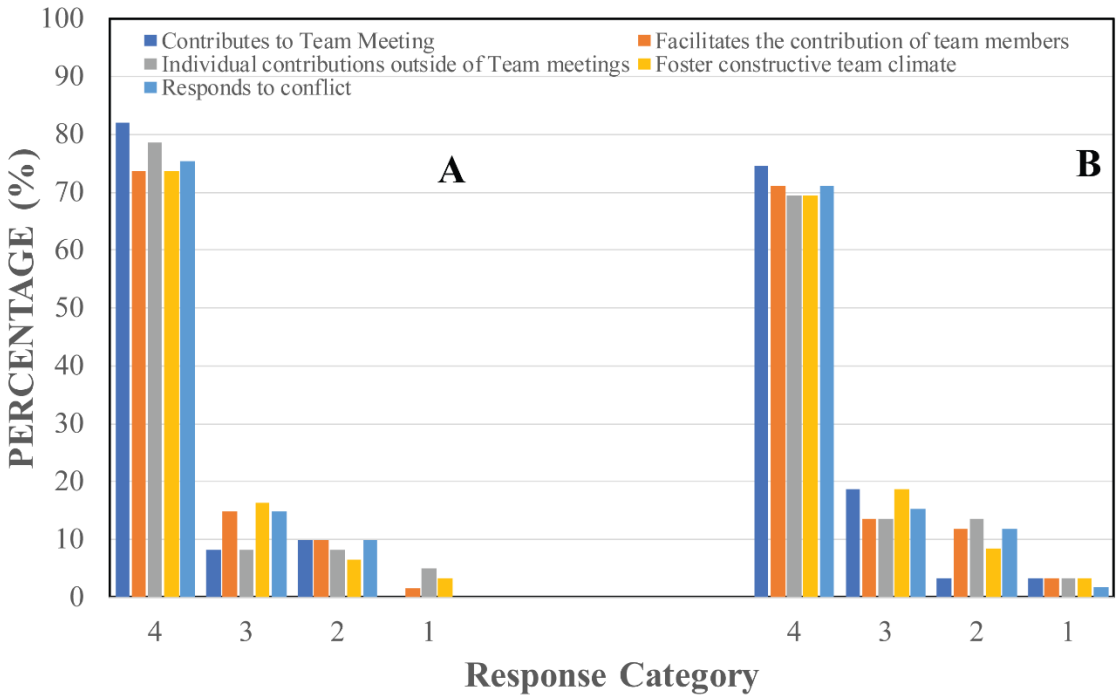

Figure 3. AAC&U survey results evaluate the performance of individual members of a group. A represents student 1, B represents student 2, and the responses were provided by student 3 who are all individuals from the same team. Results are shown for Report 4 analysis. [A total of 61 student responses were used for this data plot]

Team lead assessment forms reveal an intriguing correlation between teamwork effectiveness and workload distribution (Appendix 3.1). For the reports evaluated (reports 2 – 4), less than 10% of the groups reported an issue using the open team lead assessment form, which correlates well with the results obtained through the AAC&U evaluation tool. Positive feedback such as (1) excellent team member, (2) finished their parts on time, (3) came to group meetings, (4) participated and remained for all group meetings, and (5) provided suggestions to other team members written sections were comments obtained in the form.

When issues were reported, it seems that the group addressed them in a cooperative way as reported by the team leader in the debrief session with the instructor. For example, due to unforeseen circumstances, one of the students was absent during one class, resulting in more experimental efforts from the other two members. The work done by the absent student was replaced by a heavier load on literature review, and the team recognized the effort using the assessment form at the end of the report (App. 3.1). These results provide a qualitative perspective on the individual contributions to the team success. This form has been implemented for only one semester on which the teams were self-selected, and it seems that the connection to writing their initials in the group assessment form improves their individual commitment to participate more in report writing. Current results, however, are also balanced with the anonymous administered surveys which seemed slightly different than the completed evaluation at the end of each report.

The anonymity of the Google form provided an alternate route for the students to express their concerns and frustrations when collaborative efforts felt apart. Out of 21 groups in four different sections, four groups experienced problems during the semester. In fact, at least two of these groups were the result of a random group of left-out students during team selection. Nonetheless, if compared with the first trials of evaluations on which approximately 2/3 of the class had a significant unbalance in their team's efforts while working in the unit operations laboratory, it seems that self-selected teams had a better experience working in a group.

5. Suggested techniques for future works

The instructors recognize the availability of tools such as CATME[9], which have also been tested in the past for this laboratory; however, through this study, a shorter and faster assessment tool to perform peer evaluation was tested in a laboratory teaching environment which is primarily based on group reports. The commitment to sign a form describing the individual contributions to the report seems to foster the individual accountability and assigned efforts. Future efforts should focus on comparing different peer-assessment tools during the same semester to evaluate the efficacy of each tool. Nonetheless, this could create resistance from the students, which could hinder teaching and learning aspects of the class, and a careful approach must be taken when multiple assessments are given in a semester.

Challenges remain when the grade depends highly on a collective effort deliverable (*i.e.*, the reports). As observed, when the groups were assigned, the two stronger students, or one student, will tend to dominate the workload distribution and performance of the group in case of conflicts. Even though one-on-one discussions and meetings were implemented with most of the teams, these were not helpful, and some students did not obtain a successful learning or collaborative experience of working in groups. These symptoms correlate with the concepts of a "free-rider student" in a group [10]. Conversely, bad leaders or bossy-style leaders could affect the performance of a team in the unit operations laboratory by guiding in wrong directions or without a purpose of learning. Despite having an individual and a group grade, the authors recommend a heavy emphasis on individual contributions to motivate students who tend to depend on the stronger students when teams are assigned.

Based on the results of this work, it seems that self-selected teams led to a better teamwork dynamic in the unit operations laboratory for high performing or compatible students, but unfortunately, weak groups will always be left out (self-exclusion). Discussions of the definition of well-functioning teams should be provided to the students early in the semester, but most importantly, early in the curriculum to help the underperforming groups. Cooperative efforts within these groups can be enhanced by considering five key components: (1) positive interdependence, (2) face-to-face interactions, (3) individual accountability and personal responsibility, (4) social skills, and (5) group processing. In fact, the implementation of these aspects in working groups has been shown to advance the development of team efforts either in a class setting[5] or for undergraduate oriented-research groups[11]. Once these students reach senior year, they should be able to function effectively in a group, and the implementation of these aspects should be done in classroom settings in the early years.

At The University of Dayton, the Unit Operations Laboratory is the experiential learning experience and a capstone class for the students in the curriculum, and when forming groups,

interactive and engaging methods for every student must be provided to support team-building activities and collaborative efforts [12]. The authors, who have more than 15 years of experience teaching the unit operations laboratory course, seek to improve the engagement of the students in the future because a lack of interest in performing the experiments by spending less time in the laboratory but more time focusing on writing the reports. Other methods that are suggested for future Unit Operations Laboratories could involve active and collaborative learning (ACL), project/problem-based learning (PBL) and Entrepreneurially Minded Learning (EML) which are potential alternatives to enhance chemical engineering experiential learning [13, 14].

6. Conclusion

The use of different assessment tools for peer-evaluation was implemented on a semester in which the students selected their teams, and a comparison was made when the instructor assigned the teams using only the student team leader evaluations. With the current data, this study demonstrates that the use of individual assessment and group evaluation, both anonymous and openly written as part of their reports, can motivate students to perform better when working in groups either self-selected or assigned by the instructor. However, it is recognized that analyzing a laboratory course is complicated due to a significant amount of variability every year – from students' variability to the team selection process within a single semester. Overall, it is recommended to foster cooperative efforts by introducing expectations and goals for each team early in the semester for underperforming groups. This engagement with the underperforming groups could enhance their learning experiences in the Unit Operations Laboratory regardless of the team selection process.

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APPENDIX

APPENDIX 1. REQUEST TO EXPERIMENT FORM

Request to experiment, Unit Operations Laboratory

Keep it simple: handwritten, no additional paper, one side

Team Number _____

Names:

_____,_____,_____

Research Objective Statement (brief, include apparatus name):

Primary Safety Concerns:

Approved:

NOTES:

APPENDIX 2. Rubric for report grading

Group 1 (KKC)	REPORTS				
Experiment/Assignment	**1**	**2**	**3**	**4**	**5**
Editorial					
--Clarity (2.5)	2.3	2.1	1.5	2	
--Proper Grammar (2.5)	2.5	2.1	2.5	2	
--Proper Order/Follow Guidelines (2.5)	2.5	2.5	2	1.5	
Editorial Subtotal	7.3	6.7	6	5.5	
Editorial Subtotal Available	7.5	7.5	7.5	7.5	7.5
Key Components					
--Brief Objective/Apparatus/Procedure (2.5)	2.3	1.8	2.5	N/A	N/A
--High Quality Introduction (2.5)	N/A	N/A	N/A	2.1	
--Literature Review/Model Development (5)	N/A	N/A	N/A	4.5	
--Apparatus/Procedure/Safety Review (5)	N/A	N/A	N/A	4	
--Uncertainty/Calibration (2.5)	2.3	2.4	2	2.5	
--Data Summary (2.5)	2.3	2.3	2.5	2	
Key Components Subtotal	6.9	6.5	7	15.1	
Key Components Subtotal Available	7.5	7.5	17.5	17.5	17.5
Other					
--Abstract (5)	N/A	N/A	N/A	N/A	
--Appropriate Level (5)	N/A	4.5	4.5	4.6	
--Calculations, Analysis, and Conclusions (25)	20	20	20.5	21	
Other Subtotal	20	24.5	25	25.6	
Other Subtotal Available	25	30	30	30	35
Total	34.2	37.7	38	46.2	
Total Available	40	45	45	55	60

APPENDIX 3.1 Assessing the contribution of each member and workload distribution

Team #:___ Report #____ UO Lab section#____

Team Leader Group Assessment

The objective of this form is to provide the team an opportunity to self-assess the internal communications, division of labor, and compatibilities of working within the group. All members should be cognizant of their role (either positive or negative) in the group, but the Team Leader is responsible for reporting this assessment to the managing authority (*i.e.*, instructor). Should there be differences in opinion of how each member is assessed, group members can report incidents directly to the instructor.

Instructions: Team leader assess and fills out each member contributions (including their own) to the assigned report/experiment and overall group cohesion. Group members initial that they have seen the completed assessment.

Team Member Name:			
Team member contributions to report & experiment			
Team member contributions to group cohesion			
Initials:			

Appendix 3.2. AAC&U teamwork value rubric. Reprinted with permission from "VALUE: Valid Assessment of Learning in Undergraduate Education." Copyright 2018 by the Association of American Colleges and Universities. http://www.aacu.org/value/index.cfm.

TEAMWORK VALUE RUBRIC

for more information, please contact value@aacu.org

Association of American Colleges and Universities

Definition

Teamwork is behaviors under the control of individual team members (effort they put into team tasks, their manner of interacting with others on team, and the quantity and quality of contributions they make to team discussions.)

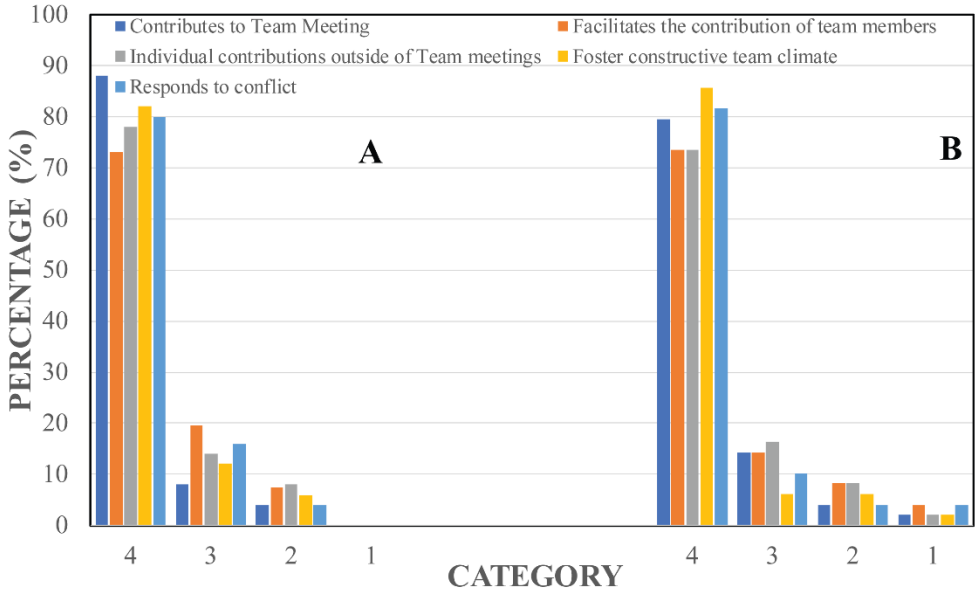
Evaluators are encouraged to assign a zero to any work sample or collection of work that does not meet benchmark (cell one) level performance.

	Capstone 4	**Milestones** 3	2	**Benchmark** 1
Contributes to Team Meetings	Helps the team move forward by articulating the merits of alternative ideas or proposals.	Offers alternative solutions or courses of action that build on the ideas of others.	Offers new suggestions to advance the work of the group.	Shares ideas but does not advance the work of the group.
Facilitates the Contributions of Team Members	Engages team members in ways that facilitate their contributions to meetings by both constructively building upon or synthesizing the contributions of others as well as noticing when someone is not participating and inviting them to engage.	Engages team members in ways that facilitate their contributions to meetings by constructively building upon or synthesizing the contributions of others.	Engages team members in ways that facilitate their contributions to meetings by restating the views of other team members and/or asking questions for clarification.	Engages team members by taking turns and listening to others without interrupting.
Individual Contributions Outside of Team Meetings	Completes all assigned tasks by deadline; work accomplished is thorough, comprehensive, and advances the project. Proactively helps other team members complete their assigned tasks to a similar level of excellence.	Completes all assigned tasks by deadline; work accomplished is thorough, comprehensive, and advances the project.	Completes all assigned tasks by deadline; work accomplished advances the project.	Completes all assigned tasks by deadline.
Fosters Constructive Team Climate	Supports a constructive team climate by doing all of the following: • Treats team members respectfully by being polite and constructive in communication. • Uses positive vocal or written tone, facial expressions, and/or body language to convey a positive attitude about the team and its work. • Motivates teammates by expressing confidence about the importance of the task and the team's ability to accomplish it. • Provides assistance and/or encouragement to team members.	Supports a constructive team climate by doing any three of the following: • Treats team members respectfully by being polite and constructive in communication. • Uses positive vocal or written tone, facial expressions, and/or body language to convey a positive attitude about the team and its work. • Motivates teammates by expressing confidence about the importance of the task and the team's ability to accomplish it. • Provides assistance and/or encouragement to team members.	Supports a constructive team climate by doing any two of the following: • Treats team members respectfully by being polite and constructive in communication. • Uses positive vocal or written tone, facial expressions, and/or body language to convey a positive attitude about the team and its work. • Motivates teammates by expressing confidence about the importance of the task and the team's ability to accomplish it. • Provides assistance and/or encouragement to team members.	Supports a constructive team climate by doing any one of the following: • Treats team members respectfully by being polite and constructive in communication. • Uses positive vocal or written tone, facial expressions, and/or body language to convey a positive attitude about the team and its work. • Motivates teammates by expressing confidence about the importance of the task and the team's ability to accomplish it. • Provides assistance and/or encouragement to team members.
Responds to Conflict	Addresses destructive conflict directly and constructively, helping to manage/resolve it in a way that strengthens overall team cohesiveness and future effectiveness.	Identifies and acknowledges conflict and stays engaged with it.	Redirecting focus toward common ground, toward task at hand (away from conflict).	Passively accepts alternate viewpoints/ideas/opinions.

APPENDIX 4. Evaluation rubric for the team lead debrief after every experiment

	4	3	2	1
Organization 15 pts	Information is presented in a logical sequence. Citations are listed. Excellent summary of the main objective and main conclusion. Slides are numbered	Information can be followed. Random citations Clear summary of results objective is mentioned and the conclusion agrees with it.	Information is not presented logically.* No citations Results are not summarized well. Objective does not lead to the conclusion	Information is missing.* No citations Seems to be put at the last minute. Unclear conclusion based on objective
Technical Content 50 pts	Excellent introduction. Scope of the work is clear. Clear model selection and explanation. Comparison of model and experimental data leads to a unique conclusion. Students recognize experimental limits Recommendations listed and suggested	Brief introduction and problem statement. Results are fitted to a model but no details on errors/assumptions are provided. Comparison of theoretical model to experimental is not clear Conclusions and suggestions can be improved.	Objective/intro are vague No error bars but uncertainty values were calculated. Results are fitted to an equation with no model comparison Conclusions are general No recommendations	No clear objective/intro No uncertainty explanation or calculations. Results are not fitted to any model (experimental data only) Data is presented with no clear explanations of the results Vague conclusion
Presentation style 30 pts	Good eye contact and excellent confidence on talking about their research Good timing (<10 mins) Excellent use of slides (flow) Answer questions with great confidence	Eye contact can be improved student is nervous Student didn't practice before but was able to convey the message Slides were used briefly Unsure about questions or answers Timing was good (sometimes rushed to cover everything)	Almost no eye contact students is anxious and nervous Student is not prepared Presentation finished at the last minute No connection between discussion and slides. Timing was off. Could improve visual aids (PPT slides)	No eye contact Student has an apathetic behavior during the presentation. Random slides were prepared. The student is not ready to answer questions. Timing was off Slides were not used efficiently
Team lead skills 20 pts	When asked, the leader knew what the accomplishments were for everyone in the group Leader has suggestions to improve team dynamics for future reports	Leader had an idea on workload distribution. Leader took responsibilities for assigning work Suggestions for future improvements are good, but Collaborative efforts are lacking	Leader does not know the workload distribution. He/she didn't lead effectively No suggestions or comments to improve their work	Leader did not assume the role Did not prepare a good presentation Did not discuss weaknesses or strengths with the rest of their teammates. No commitment

Appendix 5. AAC&U survey results evaluate the performance of individual members of a group. A represents student 1, B represents student 2, and the responses were provided by student 3 who are all individuals from the same team. Results are shown for *Report 2* analysis. [A total of 50 responses for each student were used for this data plot]



Appendix 6. AAC&U survey results evaluate the performance of individual members of a group. A represents student 1, B represents student 2, and the responses were provided by student 3 who are all individuals from the same team. Results are shown for *Report 3* analysis. [A total of 55 responses for each student were used for this data plot]