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Assessing Effectiveness of a Ground Rule System for Group Work in Large Engineering Courses

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Abstract:

Group work has become common practice in engineering education, as it allows students to learn teamwork skills while applying them to the course material. In particular, group work allows students to develop relationships among individuals, the team, and the task, as well as develop an understanding of group dynamics. Since positive group dynamics are created through team cohesion activities, much research has focused on developing activities using groupware systems. These systems enhance perceptions of the group environment by establishing common ground rules and shared expectations, but have historically been applied in the workplace rather than in an educational setting.

Building upon prior research findings that utilized team ground rules groupware systems to engineering education settings, this study assessed the repeatability, acceptability and effectiveness of using a ground rules system to improve team cohesion. In particular, the following research question was posed: 1) are previously developed ground rules systems repeatable in lower-division undergraduate engineering courses that perform group work? 2) does student team cohesion improve when team-specific ground rules are established prior to performing group projects? The system was applied to a large undergraduate group engineering project that focused on a design-build-test application of bioengineering principles using computer-aided-design. The sophomore level biomedical engineering course provided 21 teams of 5-6 students with a student contract that established which particular ground rules are acceptable given the team's culture. Students were encouraged to use their ground rules and team contract throughout the course's group project to improve team cohesion. A survey at the end of the project was used to assess the acceptability of the ground rule system to improve team cohesion, and its effectiveness was determined by comparing project scores of those who used the system to those who did not.

It was found that out of 112 respondents, 76% found that agreeing on ground rules prior to the project was useful and their team followed their chosen ground rules, and 53% of the respondents felt that their team were all very committed to the contract. Furthermore, only 12% of respondents found that some of their team members were not committed to the contract. In addition, students who were followed the ground rules system had higher scores on project performance than those who did not ($p < 0.01$). After comparing the effect of demographics such as gender, ethnicity, income, and class level, it was found that there is a significant gender bias towards males ($p = 0.011$, Pearson chi-square test statistic = 8.9625). This is an important and distinct finding from prior research, as it indicates that female students do not find ground rules systems as effective as male students do to improve team cohesion. These novel findings suggest that the ground rules system can improve team cohesion, and further validates prior findings from other institutions. However, further research is needed to understand how female students perceive and utilize ground rules systems, and how to make them more effective for this population type, particularly in lower-division undergraduate engineering settings.

Introduction:

Group work is becoming common practice in engineering education, as it allows students to learn teamwork skills while learning the course material at the same time[1]. Desirable teamwork skills developed through group work include understanding group dynamics, supporting relationships between individuals, teams, and the task, and establishing practices that build trust[2]. Furthermore, employers have found that graduates who function well in a team-based environment and have these skills are more successful in their careers as new hires[3].

In order to understand whether new engineering graduates are prepared for the team-based structure of the workforce, the American Society of Mechanical Engineers (ASME) Council on Education assessed whether college graduates have effective teamwork skills, and found that employers believe they are only marginally skilled in cross-functional teamwork skills[4]. As a result, significant research has focused on better preparing undergraduate engineers with teamwork skills through project-based group work exercises such as senior design capstone courses[3]. In particular, much research has focused on developing positive group dynamics through team cohesion activities[5] using groupware systems[6]. These systems enhance common perceptions of the group environment by establishing common ground rules and creating shared expectations that represent the culture of the team[7]. However, these systems have been historically utilized in the workplace rather than in an educational setting, and little research has been performed in applying these ground rules to undergraduate group work[7].

Related Work:

There have been a few examples of using ground rules systems in undergraduate engineering education to enhance teamwork skills and group dynamics[7-12]. For example, Sheppard et al. (2003)[8] found that the utilization of ground rules systems and peer feedback tools is important for international and virtual team-based projects, where students are geographically dispersed as they attempt to achieve interdependent organizational tasks. This is more reflective of the current global environment of business and engineering, and highlights the need for ground rules systems to foster collaboration and team development among dispersed and cross-cultural team members. Such ground rules are often used in face-to-face teams, but are arguably even more important in virtual settings such as online courses[9]. They should address topics such as what constitutes balanced and regular participation, the time requirements for responding to one another, what constitutes constructive feedback, general conflict management, and what are good decision-making procedures.

Another example of the utilization of a ground rules system in engineering education was performed by Hunter & Matson (2001)[10], where they developed a framework for experiential learning programs and workshops for industrial engineering students to learn leadership skills. To this end, they instructed their teams to develop a set of team operating rules and present their list at the close of the program. They also found that not only did this activity help team members focus on their expectations of each other and the team, but it also had the added benefit of improving their time management skills.

Other recent research[11, 12] has found that creating a team contract and establishing ground rules at the beginning of capstone senior design courses is an important tool to improve team functioning. In particular, a contract developed by students should be shared with the instructional team, as it improves the relatedness among the student teammates and the instructional teams. Furthermore, the team contract can provide guidance for the team to manage itself as well as foster autonomy. Finally, a team contract shared among the entire senior design team can promote the development of a shared mental model, which can in turn improve productivity and success of the senior design project[12].

Lastly, Whatley, J. (2009)[7] created a ground rules groupware system that supported agreeing on ground rules for student teams in a multi-year team project in a higher education setting. They found that establishing ground rules and norms at the beginning of a multi-year team project improved team cohesion, trust, and shared understanding among the students. Furthermore, the establishment of ground rules during the start of the projects motivated the students to get started on the project, which helped students start the brainstorming stage. These positive findings support further research in using ground rules systems for engineering group projects.

Although prior research has found positive findings with the utilization of ground rules systems to support team cohesion, there has been little research to support these findings in other undergraduate engineering settings. Furthermore, there has been little to no research performed to determine whether these systems are repeatable and effective in undergraduate lower-division courses, where group work is becoming more prevalent. In particular, in lower-division courses, group work is becoming an effective strategy for meeting educational objectives while introducing students to the realities of the engineering professional world[13]. It is also preferred by underserved populations[14], and continuous use of group work throughout the entire undergraduate curriculum (and not just at the senior design capstone course) is in accordance with ABET Criterion C outcomes, the ability to function in multidisciplinary teams. As a result, research in improving team cohesion in undergraduate lower-division courses where group work is now becoming common practice is becoming more important.

The purpose of this study is to address the repeatability and effectiveness of similar ground rules systems used in prior research in lower-division undergraduate engineering group work. The following sections will highlight the research questions, methods, and results of the study, which adapted the ground rules system presented in Whatley, J. (2009)[7] and applied the system to a large lower-division undergraduate engineering design-build-test course. The acceptability and effectiveness of the system to improve team cohesion at the lower-division level was analyzed both qualitatively as well quantitatively.

Objective:

As previously mentioned, this study builds upon the prior findings from Whatley, J. (2009)[7] to assess the repeatability, acceptability, and effectiveness of a ground rules system for student teams in large undergraduate lower-division group engineering projects. To this end, the following research question was posed:

1) Are previously developed ground rules systems repeatable in lower-division undergraduate engineering courses that perform group work?
2) Does student team cohesion improve when team-specific ground rules are established prior to performing group projects in lower-division undergraduate engineering courses?

Methods:

To assess the above question, the ground rules system was applied at the start of team formation in a large lecture-based sophomore biomedical engineering course that focused on the design-build-test process using computer-aided design (CAD). Specifically, students who were enrolled in an undergraduate CAD course at an R1 (highest research level) institution completed a 10-week intensive design-build-test project to develop a wheelchair lever arm for those in developing countries. Sponsored by the Free Wheelchair Mission (Irvine, CA), students were tasked with developing a wheelchair lever arm that can easily be mounted on the Free Wheelchair Mission's wheelchairs and is low in cost, as these wheelchairs are donated to those in need in developing countries. This would allow end users to drive the chair with less force, particularly for those with upper extremity weakness. As part of their CAD course, students developed an assembly model of their prototype design using SolidWorks (Dassault Systèmes, Waltham, MA), and then built and tested their prototype based on their CAD model at the end of the 10 week course. Students then "raced" each other to determine whether their prototype functioned as appropriate, and wrote a final report that reflected upon their design and redesign process. An example photo of students racing their wheelchair lever arm drivers is presented in Figure 1 below, along with the resulting CAD model.

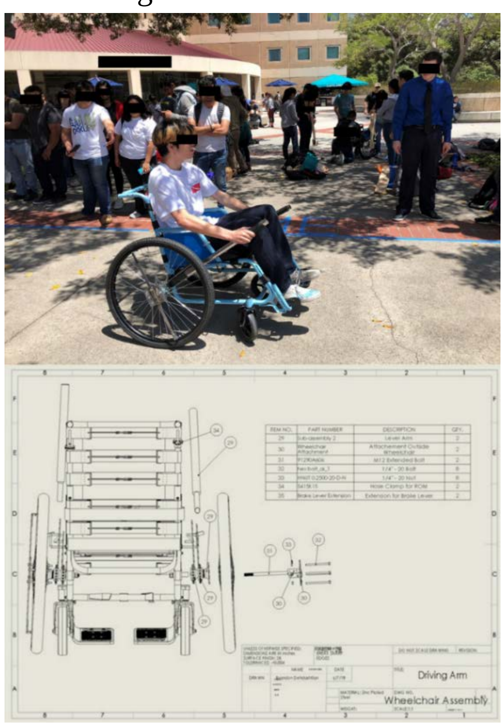

Figure 1: (top) Image of students testing their prototype on "race day", (bottom) resulting assembly model of a student team's prototype design.

Data Collection:

Students self-formed groups of 5-6 at the start of the course, resulting in 21 teams (124 students total). All students, instructor, and teaching assistants that participated in the study were provided informed consent (University of California Irvine IRB Approval Number: 2018-4211). At the start of the course, students were required to sign a team contract that established which particular ground rules are acceptable given the team's culture. In addition, students self-assigned roles among their team members, including a project manager who was responsible in making sure the team members abide by their chosen ground rules. Other student roles included a manufacturer, materials engineer, tester, lead designer, and researcher. The manufacturer was responsible for the build process, the materials engineer was responsible for the budget and materials choices during the design process, and the tester was responsible for the iterative testing process. In addition, the lead designer was responsible for the assembly of each team member's parts, and the researcher was responsible for the documentation, research, and addressing the market value of the prototype. Finally, once the roles were assigned, the students were also asked to determine regular meeting times as part of a team contract where the ground rules system was implemented.

Ground Rules System:

As part of their team contract, students were given the same list of ground rules developed by Whatley, J. (2009)[7], and were asked to choose which rules they believed are most important for their team to be successful (Table 1).

Table 1: Ground rules system adapted from Whatley, J. (2009)[7].

Number of Groups who Chose the Ground Rule	Ground Rule
18 (85.7%)	Complete Agreed Work on Time
17 (81.0%)	Inform of Non-Completion
15 (71.4%)	Read and Respond to Messages within Agreed Time
18 (85.7%)	Inform Others of Progress
18 (85.7%)	Respect Consensus Decisions
15 (71.4%)	Value Diversity
17 (81.0%)	Be Honest
19 (90.5%)	Play an Active Part in the Team
14 (66.7%)	Trust Each Other
17 (81.0%)	Respect Each Other
19 (90.5%)	Attend Meetings that Have Been Arranged
17 (81.0%)	Prepare for Meetings
15 (71.4%)	Be Punctual for Meetings
13 (61.9%)	Send Apologies if Unable to Attend

The students were encouraged to use their ground rules and team contract throughout the course's group project to improve team cohesion. In particular, the instructor encouraged the project managers of the teams to review their contract and ground rules after each phase in the design process (e.g. after the design review, the building of the prototype, and after validation testing of the prototype). A survey was then provided at the end of the project to all of the students, which was used to assess the acceptability of the ground rule system to improve team cohesion. To maximize compliance, completion of the survey awarded the student with one extra credit point towards their final grade. As presented in Table 2, the following constructs were examined using the survey.

Table 2: Constructs and resulting survey questions to assess the acceptability and effectiveness of the ground rules system on team cohesion.

Construct	**Question**
Acceptability of ground rules system	Did your team follow your ground rules?
	If yes, how did you use them? If no, why not?
Perceived utility of ground rules system	Did you find that agreeing on ground rules was useful?
Potential improvements for ground rules system	Are there any other ground rules not listed in the student contract that you found to be important and should be included? If yes, what are they?
Perceived effectiveness of ground rules system	What effect did the student contract have on your team?
Level of team cohesion	Please rate your colleagues' commitment to the contract.

As seen in Table 2, students' perceptions of the ground rules system were ascertained using both categorical items (e.g. "yes" or "no" or 4-point Likert scales) and open-ended questions. Both the positive and negative nature of the ground rules system was examined, as well as the potential improvements that can be made. This helped determine which key factors led to student acceptability of the ground rules system. In addition, the perceived utility and acceptability of this system was assessed by comparing project scores of those who reportedly used the system to those who reported that they did not use the system throughout the project. This was done by quantitatively analyzing the online survey results. To this end, since the project scores had a bimodal distribution type (Figure 2), and we cannot assume sample independence as team cohesion effects project performance, the Wilcoxon signed-rank test was utilized for both tests. The Wilcoxon signed-rank test is a non-parametric method of the paired Student's t-test.

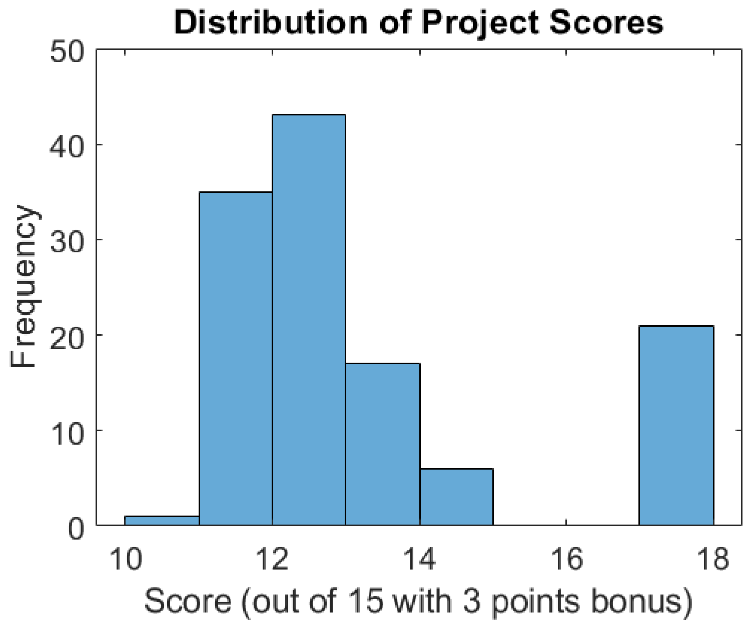

Figure 2: Histogram of the final project scores, showing a bimodal distribution and thus a Gaussian distribution cannot be assumed for statistical analysis.

In addition to assessing the perceived utility and acceptability of the ground rules system quantitatively, the level of team cohesion was also quantitatively analyzed. This was done by comparing the level of team cohesion (a four-point categorical value: “They were all very committed to the contract”, “They were all somewhat committed to the contract”, “They were all not committed to the contract”, and “Only some members were committed to the contract”) to the final project scores. For this analysis, the Kruskal Wallis test was performed due to the fact that the assumptions required for ANOVA were violated. In particular, since it was found that the final grade scores had a bimodal distribution type (Figure 2), and thus the variable could not be considered as Gaussian, the Kruskal Wallis test was chosen as it is a non-parametric method of ANOVA. It is also the generalized form of the Mann-Whitney test, as it permits two or more groups (four in this case) to be compared for statistical significant difference.

Other variables that were quantitatively explored in terms of their relationship with the level of team cohesion achieved using the ground rules system include categorical demographic variables such as sex, low income, current class level (sophomore, junior, or senior), and race. Using cross tabulation, Pearson chi-square tests were performed to determine whether the categorical variables were associated or independent.

Results:

As seen in Table 1 above, most student groups found the majority of the ground rules presented to be important in their team’s culture. Specifically, only nine out of the 21 groups found that all ground rules presented were important, demonstrating that many of the groups chose only those rules that they believed were important to their particular team's culture. Of these rules, the majority of groups found the following rules to be most important for their team's culture:

1. Play and Active Part in the Team
2. Attend Meetings that Have Been Arranged

Of the ground rules that were chosen the least by the groups, "Send Apologies if Unable to Attend" was the least chosen rule. In addition, the following rules were also the least likely to be chosen as important for the individual groups:

1. Read and Respond to Messages within Agreed Time
2. Value Diversity
3. Trust Each Other
4. Be Punctual for Meetings
5. Send Apologies if Unable to Attend

Repeatability of the Ground Rules System:

It was found that the ground rules system presented by Whatley, J. (2009)[7] is repeatable in large lower-division undergraduate courses. By presenting the ground rules system along with the team contract, students were able to formally create teams, assign roles, create scheduled meeting times, and negotiate which rules were important to their own unique team's culture. Furthermore, it helped them get started on the project and begin the brainstorming stage of the design-build-test process. For instance, through qualitative assessment of the students' perceived utility of the ground rules system, students reported that:

"The student contract helped make sure our team was held liable for the amount of work that everyone put in. This was beneficial because at the end everyone participated in some way and all the work did not fall on everyone."

"The student contract helped my team and myself know what to do in terms of making mistakes. Whenever we ran into problems, we thought back to the contract and focused on [them]."

"The student contract had a serious effect on my team. It allowed us to shift our mindsets and take this project as serious as a job."

"[The contract gave our team] a sense of cohesiveness and accomplishment of getting the first steps starting to the project."

"I believe it helped students understand that accountability would be monitored, discouraging students from being the "slacker" in the group."

These comments highlight the utility and repeatability of a ground rules system to help students get started on the project, as well as provide students with the mindset that a class project should be treated similarly to a project being performed in the professional world. In addition, many students reported that it required students to better distribute the work of the project, and discouraged students from "slacking off".

The comments from the survey that discussed the negative nature of the ground rules system and potential improvements that can be made also highlighted that most students found the ground rules that were presented to be sufficient. However, some students mentioned that there should be a time requirement agreement as well as a level of quality of the contributed work expectation added to the ground rules. In addition, others believed that there should be a rule that would include a willingness to ask other group members for help when they need it. For instance, some students mentioned that:

"Group members need to make sure their accomplished work has certain quality."

"Each person should contribute a minimum hour."

"I think something additional should be added about how to handle problems. Either problems people have with the design or with other group members."

"One rule that we made ourselves that was not listed is to be willing to ask others for help."

"I think something that needs to be added is assisting your group mates when they need help."

Acceptability of the Ground Rules System:

Out of the 124 students who participated in the class, 112 students responded to the online survey. Their demographic data is presented in Table 3 below.

Table 3: Demographics of the study participants who completed the online survey.

Number of Participants: 112	
Low Income	28 (25.0%)
First Generation	29 (25.9%)
Females	58 (51.8%)
Hispanic	26 (23.2%)
Asian American	56 (50.0%)
Underrepresented Minorities	28 (25.0%)

It was found from the online survey results that out of the 112 participants described in Table 3 above, 76% found that agreeing on ground rules prior to the project was useful, and 77% of the respondents reported that their team followed their chosen ground rules (Figure 3). Furthermore, after comparing the perceived acceptability and utility of the ground rules system to project score using the Wilcoxon signed-rank test, it was found that there was a statistically significant difference between project performance of those who followed the ground rules to those who did not ($p = 5.72 \times 10^{-6}$), i.e. perceived acceptability. There was also a statistically significant difference between project performance and perceived utility of the ground rules system ($p = 4.12 \times 10^{-5}$). This demonstrates that those who found the ground rules system useful and who utilized them with their team throughout the project performed better than those who did not.

After comparing demographic data against all survey results (i.e. perceived acceptability, perceived utility, level of team cohesion), it was found that there were no statistically significant associations between low income, current class level, or race. However, there was a statistically significant different association between the gender and the acceptability of the ground rules system ($p = 0.011$, Pearson chi-square test statistic = 8.9625). As seen in Figure 4 below, there was a larger variance between males who found the ground rules useful versus not compared to females. Furthermore, a higher number of males found the ground rules system useful. This is significant, as there were almost an equal number female and male participants (see Table 3).

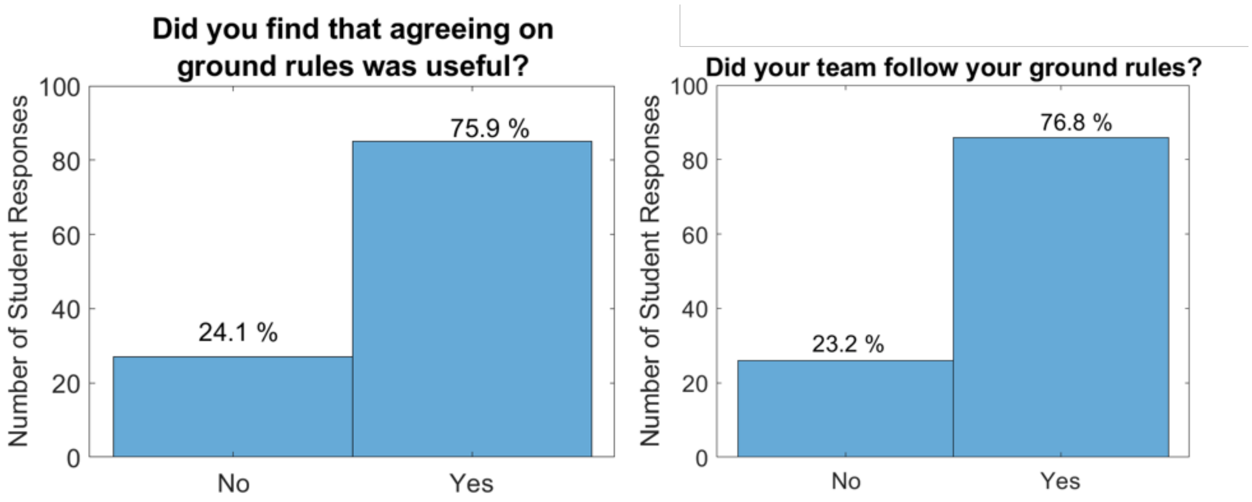

Figure 3: Histograms of (left) the perceived utility and (right) the perceived acceptability of the ground rules system.

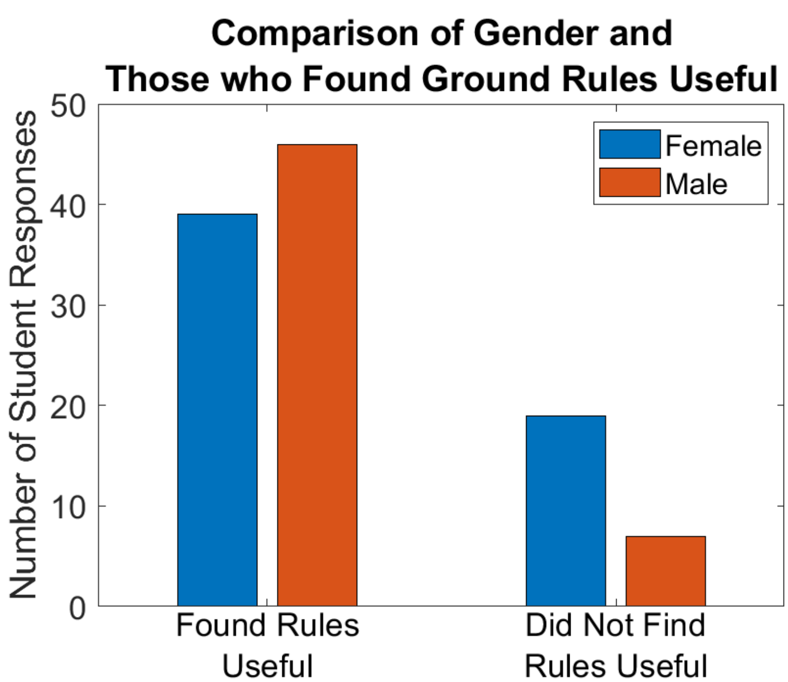

Figure 4: Comparison of gender and the acceptability of the ground rules system.

Effectiveness of the Ground Rules System on Team Cohesion:

To compare the effectiveness of the ground rules system on team cohesion, the level of commitment of the team members to the contract was compared with project performance using the Kruskal Wallis test. There was no statistically significant difference between project performance and level of team cohesion ($p = 0.5$). However, it was found that no students felt that none of their teammates were committed to the contract.

When comparing the number of students and their perceived level of team cohesion, it can be seen that the majority of students felt that their entire team were all committed to the ground rules system and team contract. In particular, 53% of the respondents felt that all their team members were all very committed to the contract, and 35% of students felt that all their team members were somewhat committed to the contract (see Figure 5). Furthermore, only 12% of the respondents found that only some of their team members were committed to the ground rules that they had agreed upon given their team's culture.

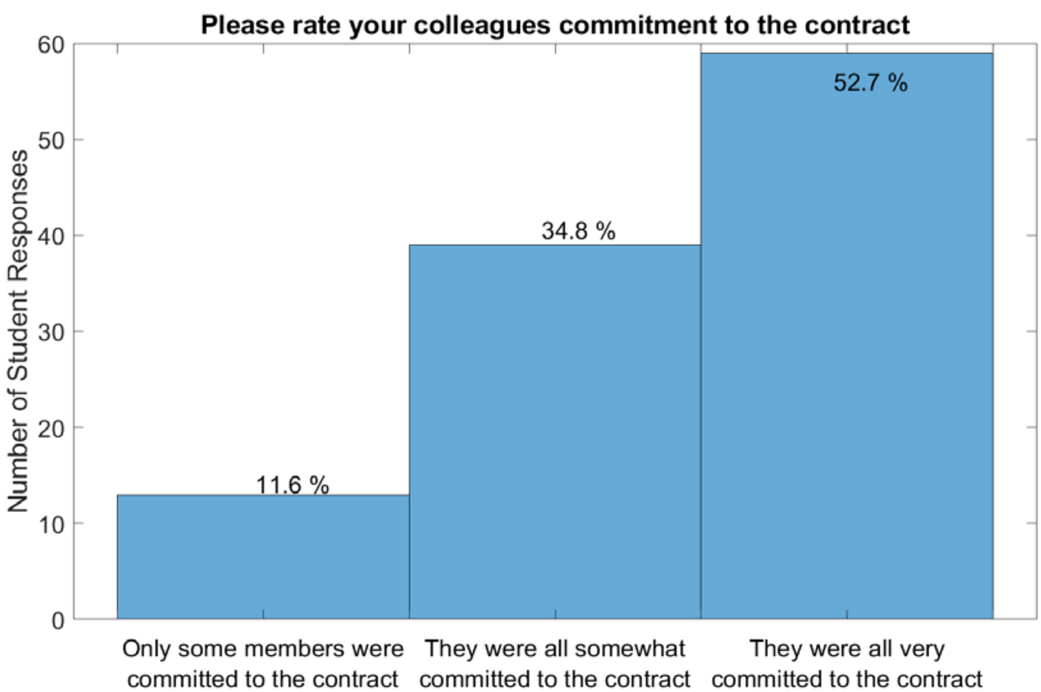

Figure 5: Perceived level of team cohesion as determined by assessing the level of the team members' commitment to the team contract and ground rules system.

Discussion:

The results of this study show that previously developed ground rules systems[7] are repeatable and effective in large lower-division engineering courses. This is significant, as little research has assessed the repeatability of previously reported findings on groupware for team cohesion improvement in lower-division educational settings. In addition, since group work is becoming an effective strategy for meeting educational objectives and ABET's Criterion C outcomes (the ability to function in multidisciplinary teams), the use of ground rules systems to improve teamwork skills is becoming more prevalent in lower-division engineering courses. As a result, there is an increasing need for using and refining ground rules systems in lower-division courses.

The qualitative analysis of the study suggests that the ground rules system assisted students in getting started on the project work and begin the brainstorming process. Furthermore, it helped students develop more professional teamwork skills throughout the project, and provided them with better insight into how to perform work distribution within a team. These skills are important for undergraduate engineers to develop early in their careers, as recent research on graduates across engineering disciplines[15] suggest that strong teamwork skills are most important for graduates entering the workforce to be successful as new hires[3].

In addition to the positive qualitative findings, the quantitative analyses also produced positive results. The results presented above on the perceived acceptability and utility of the system showed that those who utilized and followed the ground rules system had an improvement in project performance. These findings suggest that the ground rules system can improve team cohesion, which can in turn improve project performance. It also suggests that team contracts and ground rules systems are important in developing teamwork skills in undergraduate engineers, and can have a positive impact on their educational performance.

Another significant finding from this study that has not been shown in prior ground rules system research is that there is a significant association between gender and the acceptability as well as utility of the ground rules system. In particular, it was found that males had a higher acceptability level of using the ground rules system than females. This may be due to the cooperative learning environment of establishing ground rules, as it is a "structured, systematic instructional strategy in which small groups work together toward a common goal"[16]. In particular, previous research[17] has found that cooperative learning through group work can improve gender bias performance by creating heterogeneous groups. Since the ratio of females to males was almost equal in this educational setting, the majority of groups were heterogeneous in terms of gender. As a result, it would be expected that there would not be a gender bias associated with the utility and acceptability of the ground rules system. Thus, this found gender bias requires further research, as it is unclear why the ground rules system had a lower perceived utility and acceptability among female engineering students.

In addition to further research to elucidate the gender bias associated with the ground rules system, other improvements should be made to the ground rules system so that it is more appropriate for lower-division engineering group work. For instance, as mentioned in the results section, although the majority of students found the ground rules to be sufficient and encompassed the rules that were important to the individual groups, few students mentioned that additional rules should be included. These include a minimum time requirement, a level of quality of the contributed work expectation, and a willingness to ask other group members for help when they need it. In addition, in order for students to understand how to use the ground rules system, there should be a "mock conflict" assignment for students to learn how to implement the ground rules system and make all team members responsible for their actions when team cohesion is low. This may improve project performance and teamwork skills in those who did not find the ground rules system useful. In addition, for larger lower-division group projects that are term-based, the ground rules system should be reflected upon and adjusted by the group mid-project so that it better fits the developing culture of the student teams. This may improve the utility of the ground rules system by each of the team members as well as the level of team cohesion throughout the project.

Conclusion:

In summary, use of a ground rules system is repeatable at the lower-division undergraduate level and are effective at improving team cohesion. The positive findings from this study suggest that the ground rules system can improve team cohesion, and further validates prior findings from other institutions[7]. Furthermore, the positive effect of the ground rules system on project performance in those whose teams followed the ground rules system throughout their project highlights the need for a team contract and ground rules to be established prior to performing group work in a classroom setting. However, future research is required to understand how to make ground rules systems more effective in perceived team cohesion among female student populations. As group work is becoming more prevalent in lower-division engineering courses, ground rules systems that are inclusive across all genders and demographics may provide a scalable technique to improve teamwork skills in future professional engineers.

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