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Constructive Controversy: Optimizing Decision Making in Engineering Design Teams

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Constructive Controversy: Optimizing Decision Making in Engineering Design Teams

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Abstract

Constructive controversy is a method for deliberately creating discussions within a team to expose different ideas and perspectives. This method has been used extensively in fields such as business and economics, but its use in engineering is limited. In this study, the effects of utilizing constructive controversy during the team design process in an engineering course were investigated. A constructive controversy module was developed, and student surveys were conducted to quantify the perceived efficiency of teamwork. Results show that students who are trained in and apply constructive controversy develop better conflict resolution skills compared to the control group. Survey results also indicate multiple areas in which teamwork skills could be improved in future iterations of the course, including team dynamics and equal contribution from all members in making major decisions.

Introduction

Decision-making in teams has been an important topic in business and education for many years [1], [2]. Intellectual conflict can prevent teams from making coherent and efficient decisions. However, directed constructively, it can also be a great source of creativity and innovation in engineering design [3], [4]. Constructive controversy is a method developed to systematically expose intellectual conflict among team members and create a collaborative atmosphere fostering different perspectives.

Constructive controversy is implemented in multiple ways. One of the most common implementations consists of dividing the team into two or multiple sub-teams. For a design problem, each sub-team proposes a design solution and presents their design to the other sub-team. The second sub-team needs to find the weaknesses and implementation issues of the design and provide constructive criticism. Once both sub-teams have presented their design and received the feedback, all team members come together to make a final design decision based on the discussions. Constructive controversy is an alternative to other team decision-making methods such as structured debate, concurrence seeking, and individualistic approaches. In structured debate, individuals propose ideas that are incompatible with each other, and there is commonly an external judge who chooses the best idea. This method may create unhealthy dynamics in the team and reduce the team's independence. Concurrence seeking entails avoiding disagreements and discussions, which frequently results in loss of diversity in ideas and solutions [3].

Constructive controversy has been used to optimize team decision-making in several fields, including business, finance, and medicine [5], [6]. Limited studies of constructive controversy in

the field of engineering demonstrate promising results in terms of cognitive processing and learning outcomes [7]. In this work, we focus primarily on the effect of constructive controversy on multiple aspects of teamwork in engineering, including design decision-making, conflict resolution, and team dynamics such as open communication, respect, clearly defined roles, and sharing a common goal. Our population consists of 156 engineering students enrolled in 7 sections of the course *Introduction to Engineering*.

Methods

Setting

The study was conducted in a first-year *Introduction to Engineering* course. The course met for approximately three hours weekly and was led by four instructors across seven sections for a total of 156 enrolled students, most of whom were first-years. The class consists of multiple activities related to different disciplines of engineering, including electrical, mechanical, and civil engineering, as well as computer science. Some of these activities involve design decisions. Students also work on a comprehensive final project, in which they design and build a benchtop wind turbine created with prototyping materials (e.g., wood, cardboard, etc.), and monitored with an Arduino. Some of the activities, as well as the final design project, are executed in teams consisting of 3–4 students.

The first half of the semester consists of scaffolded lab tasks such as programming the Arduino, building the structure, and creating a circuit, which are then combined and applied to create the benchtop turbine.

Constructive controversy module

An instructional module on constructive controversy was implemented in three of the seven course sections (hereafter referred to as the intervention group, n = 71 students) during the first half of the semester during a lab on structural truss design. The module included a presentation outlining constructive controversy as a method for making design decisions in teams (Figure 1). The students were tasked with applying constructive controversy to decide whether they should create their trusses by laser cutting draft board or hand-fabricating with balsa wood. Per the constructive controversy framework, students in each group were divided into subgroups 1 and 2 to present solutions A and B, respectively, where solution A was laser cutting and solution B was construction by hand. Students in the control group (the four other course sections, n = 85 students) were not introduced to constructive controversy but still decided whether to laser cut or construct their truss by hand. Regarding the final project, which consisted of designing and building a benchtop wind turbine, students exposed to the constructive controversy module used the method explained above to decide on the design of the turbine.

The student teams implemented the activity in a variety of ways. Some groups followed instructions exactly—they advocated for/against a specific design option and ultimately chose a design with a collective agreement. These teams used the constructive controversy method as intended, and their results were as expected. However, a few groups went through an informal discussion first to select their design options, and then all four team members discussed the arguments for/against each design option. This second method is not precisely as the constructive

controversy theory intends, but it did provide a basis for a structured discussion about the design options.

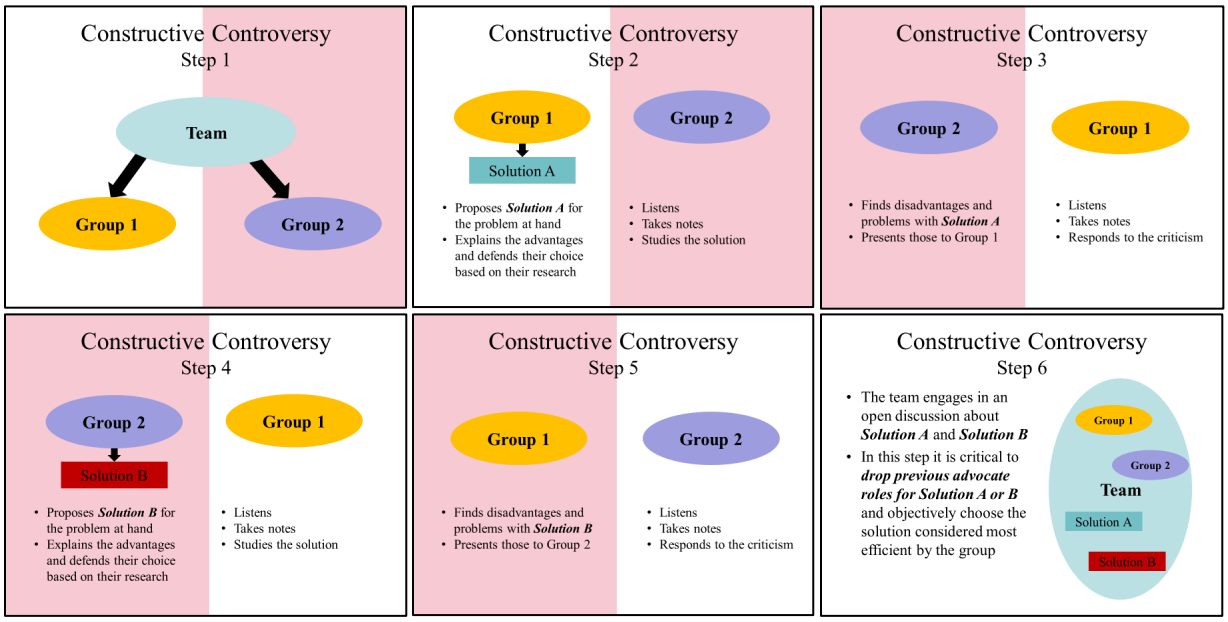

Figure 1. A slide summary of the constructive controversy presentation module.

Student surveys

Student surveys were administered to quantify multiple parameters including design success, teamwork efficiency, and individual learning during teamwork before and after constructive controversy training at three points in the semester: (1) before constructive controversy was introduced in class (pre-lab); (2) after the class module on constructive controversy (post-lab); and (3) after the completion of the final project (post-project). For the intervention group, questions were included in the post-survey to specifically evaluate constructive controversy. Likert-scale type questions were asked and are provided in Table I.

Of the 156 enrolled students, 118 students completed the pre-lab survey, 112 completed the post-lab survey (58 in the control group and 54 in the intervention group), and 77 completed the post-project survey (21 in the control group and 56 in the intervention group). For students who completed the surveys more than once, only the last response was included in the analysis and the repetitions were eliminated.

Table I. Student survey questions and scale

Category	**Question (Scale: 1 (Strongly agree) – 5 (Strongly disagree))**
Team dynamics (Open communication, respect, clearly defined roles, and sharing a common goal)	1. Team members communicate openly.
	2. Each team member has a clearly defined role.
	3. Team members treat each other with respect.
	4. All team members work towards a common goal.
	5. Team meetings are very productive.
	6. The team has methods in place to measure the team progress on a regular basis.
Conflict tolerance and resolution	7. Conflict of ideas rarely happen in the team.
	8. Team members can resolve conflicts effectively.
	9. The team has a systematic method for resolving conflicts.
	10. I am most comfortable working in a team with minimum conflict of ideas.
	11. I try to avoid conflict in teams by agreeing with other team members, even when I have a different opinion.
	12. Conflict of ideas is a beneficial part of teamwork.
	13. I can communicate my ideas effectively even when there is a conflict.
Design decision-making	14. All major decisions should be unanimously agreed on by all group members.
	15. All team members contribute equally in making the major decisions.
	16. If all group members cannot agree on a decision, the instructor should help the group decide.

Data Analysis

Statistical analysis was performed on survey data to study any possible changes in the perceived team efficiency as a result of applying constructive controversy. The following outcomes were investigated: design decision making, conflict resolution, and team dynamics. Team dynamics includes components such as open communication, respect, clearly defined roles, and sharing a common goal. Comparisons were made between the following data sets: before constructive controversy was introduced in class (pre-lab); after the class module on constructive controversy (post-lab); and after the completion of the final project (post-project). In addition, intervention and control groups were compared to study possible differences. Likert-type scale questions were converted to numeric scores (1 = strongly agree, 5 = strongly disagree). Two-tailed t-tests were performed assuming a significance level of 0.05 to find statistically significant differences.

Results & Discussion

Constructive Controversy Improved Students' Reported Ability to Resolve Conflict

A reduction of 0.26 was observed (from average of 1.72 before training to 1.46 after training, p-value: 0.024) for Question 8, "Team members can resolve conflicts effectively," for the intervention group after constructive controversy training (Figure 2), and it was retained throughout the semester with a reduction of 0.28 (p-value: 0.021) comparing the pre-lab and post-project surveys. The same question did not yield any significant change in the control group. This question corresponds to conflict resolution, and the results show the effectiveness of the constructive controversy module in improving students' ability to resolve conflict among team members. Regarding the other outcomes, namely design decision-making and team dynamics, the data was inconclusive; no differences in mean Likert-scale ratings were statistically significant.

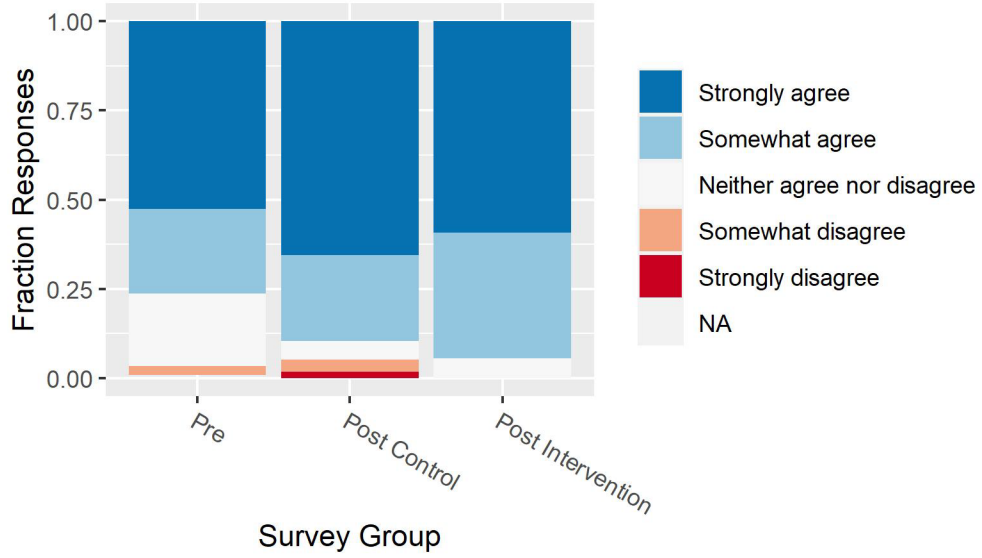

Figure 2. Likert-type data for Q8 "Team members are able to resolve conflicts effectively." Columns from left to right represent: all student response pre-lab (118 students), control group response post-lab (58 students), and intervention group response post-lab (54 students).

Student Comments Display Perspective Differences

Student comments also reveal some differences in how the intervention and the control group perceive conflict and decision making. It seems that students in the intervention group are more open to acknowledging conflict and seeing it as a growth opportunity. For instance, a student in the control group writes: "Our form of finding solution is like an idea hotpot. All ideas goes [sic] to the table, and a consensus is reached when comparing with each other." On the other hand, the following two comments are from students in the intervention group, embracing conflict explicitly: "I think if everybody is passionate about something, conflict will arise at some point and as long as the group can keep the overall goal in mind and remember we're all there to get the best result, that conflict is not only okay but useful." and "If my team never had any disagreement, we would have been significantly less productive and would have made a much less interesting wind turbine." These comments suggest that students exposed to constructive controversy perceive group conflict as an advantage rather than a hindrance.

Survey Results Revealed Other Opportunities for Teamwork Improvement

Final survey results were compiled from students in both the control and intervention groups as there were no statistically significant difference between the two. The survey results elucidate some areas in which teamwork effectiveness and satisfaction worked well and could be improved within the course. Most students (>50%) strongly agreed or agreed with most statements with the exception of two (Figure 3). Most students (74%) disagreed with the statement that "all team members contribute equally to making the major decisions" (Figure 3), suggesting there was an imbalance in team contributions. This finding suggests that future instruction on team effectiveness should include more emphasis on shared decision making. In addition, it may be beneficial to add methods to measure each member's contribution to the decision making process and track it throughout the semester. The other question in which students were split in their responses was "I try to avoid conflict in teams by agreeing with other team member, even when I have a different opinion" (Figure 3). Anecdotally, there did appear to be strong decision-makers within the student groups. To address this problem, it may be beneficial to add a module to promote consensus decision-making in teams in contrast with single-leader decision-making [8].

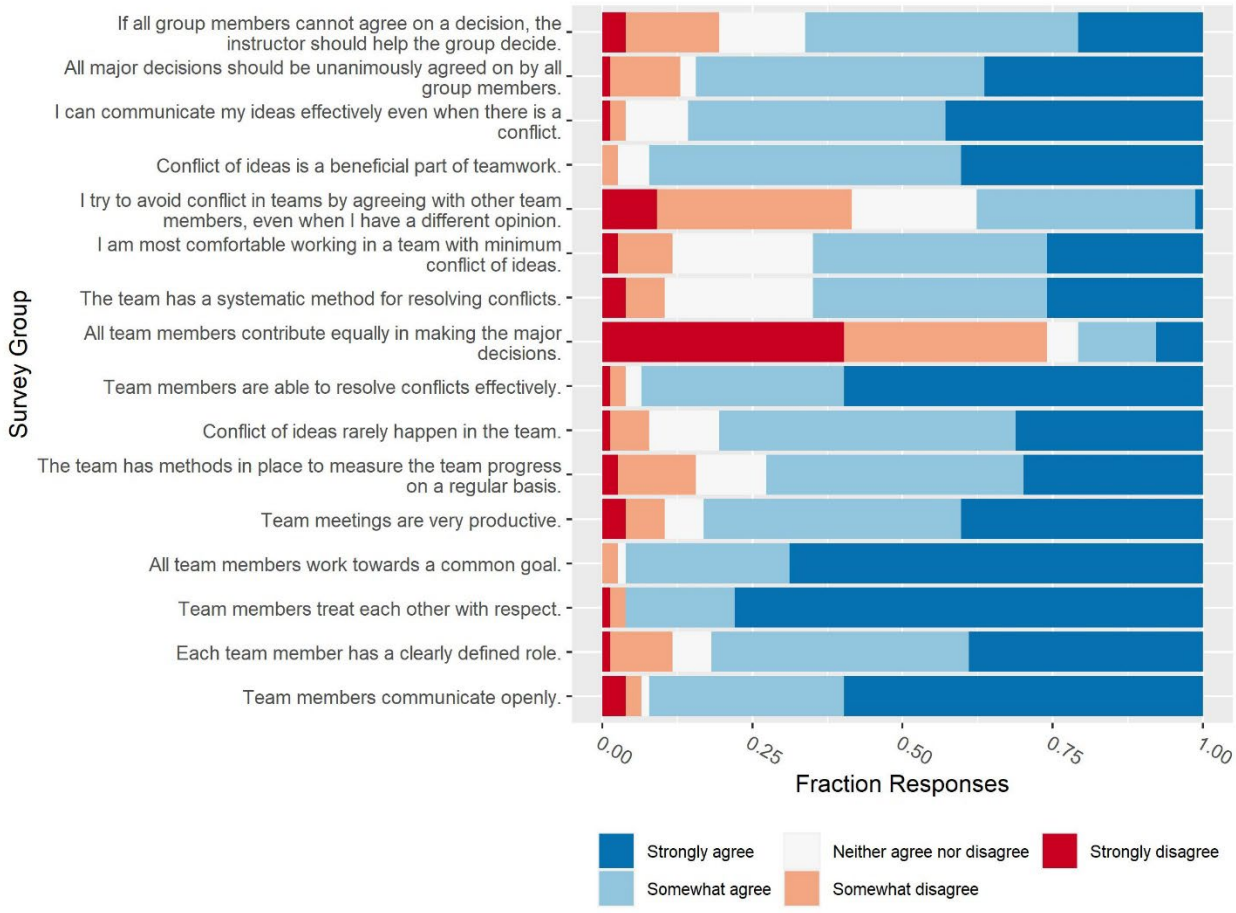

Figure 3. Survey results for all students (combined for control and intervention groups, n = 21 and n = 56, respectively) after completing the team-based design project (n = 77 students).

Conclusions

Overall, the educational module on constructive controversy improved students' reported ability to resolve conflict when comparing the intervention group versus the control. Other aspects of teamwork (design decision-making and team dynamics) were not substantially affected by this intervention. However, the study did uncover one area that could use further improvement in the course, which is guiding students to make decisions collectively. Ample opportunities exist for future work, including examining how perceived teamwork interactions in the constructive controversy module may vary across demographics and how positive effects of constructive controversy can be sustained more consistently long term.

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