ACHIEVING HIGH PERFORMING ENGINEERING DESIGN TEAMS: A CURRICULUM INTERVENTION STUDY

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Abstract *— A study was conducted to measure the effect of high performing team skills training on the performance of design teams during an industry sponsored engineering design project. The design project was a part of a first year engineering course at The Pennsylvania State University. High performing team skills were taught to one half of the sample design teams during three different two hour "intervention" sessions. The intervention sessions included: (1) an earthquake exercise, (2) a role playing exercise, and (3) an after action review. Team performance was measured using team quizzes, peer evaluations, and a blind evaluation of the project work. In addition to the intervention results, plans to further the research are discussed.*

Index Terms — Efficiency of product design teams, high performing team skills training, performance evaluations.

INTRODUCTION

The contemporary borderless economy brought on by globalization has increased the pressure on companies to manufacture customized products and to manufacture them in a cost-efficient and time-efficient manner due to the highly competitive environment of the global marketplace. Custom product manufacture requires increased efficiency in the product design process, which relies heavily on the product design/engineering team's efficiency. Although the need for teamwork in the product design process is widely recognized, improving the efficiency of design teams remains a formidable challenge in both industry and the classroom where future design engineers are being trained.

Katzenbach and Smith (1993) categorized the performance of teams and defined those teams performing at an extraordinary level as "high performing teams". In addition, Smith (2000) discussed the development and consequences of high performing team traits in classroom groups or teams in the engineering education setting. The authors believe that formal teamwork training is a valuable and often neglected part of the engineering education process. Thus, a preliminary assessment was conducted during the Spring 2001 semester at The Pennsylvania State University to measure the effect of high performing team skills training on the performance of design teams during an industry sponsored engineering design project. The industry sponsored design project is one component of the Engineering Design and Graphics 100 course (ED&G 100), a first year engineering course taught to all engineering students at The Pennsylvania State University. The results of this preliminary assessment are the focus of this paper.

METHODOLOGY

ED&G 100 is a first year engineering course with an enrollment of more than 400 students each semester. The major course objective is to develop sound problem solving skills early on in the student's education. This is accomplished through skill development (e.g., CAD skills) and a number of design projects that endeavor to integrate the student's mathematics and science knowledge to solve engineering problems. Among these projects the final project, which is industry sponsored, is utilized to create an atmosphere of "an actual working environment" for students via a real design project.

A typical ED&G 100 class size is 32 students, which allows for eight design teams of four students each per course section. To date, several team forming methods have been applied such as random selection, student selection, and clustering based on students' interests. No matter which team selection method is employed, teamwork related problems are frequently encountered affecting the design team's performance. Thus, it was hypothesized that the inclusion of high performing teams skills training can improve design team performance because engineering students receiving this training will not encounter many team work problems and consequently will perform better than colleagues who have not received the training. Moreover, it was hypothesized that students receiving the high performing team skills training and education at regular intervals during the design project would perform better than students who received such training only once. To test these hypotheses, the high performing team skill training was given to a randomly selected sample of one half of the design teams in two sections of ED&G 100 as described in further detail below.

During the six week preparatory phase of the ED&G 100 course, preliminary four-student design teams are formed to work on designing a weighing system using

strain gaged beams. During this phase, students experience the pressure of working as a team for a deadline and a payoff. Performances are measured via team quizzes and design demonstrations. For the quizzes, teams are given only fifteen minutes to answer the questions that would otherwise take one person an hour to answer. The primary purpose of this preparatory phase is to give student designers an initial experience of product design via teams. In addition, the concept of team quizzes requires that students learn to rely on other team members.

After the preparatory phase is completed, new design teams are formed, and an eight week long industry sponsored design project is given to the design teams. However, for two sections of the spring semester 2001 ED&G 100 course, a deviation to this format was made to allow the "intervention" of high performing team skills training to half of the design teams in those two sections. Eight design teams comprised of four students each were formed in each of the two course sections by random selection of students. Next, four of the eight design teams within each of the two course sections were randomly selected to receive high performing team skills training intervention. During team formation, gender, GPA and other team member characteristics were not taken into account despite the confounding effect that they could have on team performance.

The industry design project for the Spring 2001 semester was sponsored by Marconi Communications Inc. The objective of the design project was to design a shipping container to house the Marconi Communications BXR-48000 switch, which weighs 700 lbs and has dimensions of 73.5 x 21.2 x 23.62 in. The crate is for use during manufacture of the switch and shipment to the end user. Other design requirements for the crate included the ability to maneuver the crate with only two people without using a forklift and the ability to reuse the crate. The design project and its objectives were conveyed to all 16 design teams at the same time. Each team was given eight weeks to develop their design solution. All teams were instructed to act during this time as if they were companies competing to get Marconi's shipping crate business with their solution. Also, they were informed that during this time they would get help from one of two available project consultants. One of the two consultants provided engineering problem solving assistance to half of the teams as is typically provided for the ED&G 100 industry sponsored project, while the other consultant provided the other teams with three high performing team skills training interventions.

HIGH PERFORMING TEAM SKILLS TRAINING AND PERFORMANCE EVALUATIONS

The skills training offered to the randomly selected sample of eight design teams was varied, and in general, the training and education became more complex with each intervention. Each of the three interventions lasted approximately 2-hours, and a brief description of the content of each intervention is described below.

Intervention 1— Earthquake Exercise: The first intervention consisted of a simple earthquake exercise used to demonstrate that individuals working in teams typically perform better than individuals working alone on the same task. This intervention was conducted after the design project was given to the design teams. The teaching point reinforced was that teams produce better results than individuals.

Intervention 2 — Role Playing of Group Development Stages: The second intervention was conducted during the fourth week of the final design project. During this intervention the consultant introduced the stages of group development—forming, storming, norming, and transforming/high performing. Following this introduction, each team was asked to develop a role play scenario depicting a specific stage of development, i.e. one team developed a scenario and acted-out the forming stage, one team role-played the storming stage, one team role-played the norming stage, and finally, the other team role-played the transforming/high performing stage. Though initially uncomfortable with the notion of role playing, the student teams performed well and their role plays were consistent with the stage of group development that they were required to act-out. Their discomfort seemed to involve their unwillingness to engage the heretofore unfamiliar concepts of group development. The teaching point reinforced was that teams undergo a tangible, somewhat predictable developmental process and that at times group development is uncomfortable.

Intervention 3 — After-Action Reviews (AARs): This intervention was conducted during the seventh week of the final design project. Design teams were led in a brief discussion of the theory, practice, utility and execution of AARs. The discussion included the introduction of a 3-step method to (1) review & analyze what went well, (2) review & analyze those things that did not go well, and (3) offer recommendations & suggestions for improving those things that did not go well during team projects. After the discussion of the AAR process, student teams were then required to conduct an internal AAR to evaluate their own team's performance up to that point of the design project. The students valued the opportunity to engage in meaningful team analysis using the 3-step AAR method. They reported their findings to other groups and, predictably, came to understand that other teams shared similar problems and successes. The teaching point reinforced was that self-assessment is a useful technique for monitoring and improving the performance of teams.

Performance Evaluations — Design team performance for the teams that received the training and for

those teams that did not receive training was measured using team quizzes, design demonstrations (during which designs were evaluated by peers), and a blind evaluation of each team's design report. Peer evaluations of contribution levels within teams were also used as a performance metric. The grading weight of the team quiz was 5%, the weight of the peer design evaluation was 23.75% and that of the blind evaluation was 71.25%. These weights were used to establish a project grade for each design team. However, for each team member's grade, the other team members were asked to rate the contribution of that person to the team's design solution. Their contribution grade was then used to establish a multiplier to determine their project grade. Thoroughness of the project report, timeliness of the project report submission, compliance to project requirements, and utilization of engineering problem solving skills were used as criteria for project performance evaluations.

RESULTS

Despite the initial complaints for changing their teams by randomization before the final project, students were not vocal about team related problems throughout the project. The length of time for each intervention was about right: 2-hours per intervention was an adequate amount of time for the training and education. The intervention topics were appropriate - - particularly the earthquake exercise and the AAR exercise. Students were far less enamored with the role playing exercise. Some resistance was encountered during this intervention from a few students with statements such as: "Why are we learning this stuff? or "We don't want to be leaders, we want to be engineers!". Nevertheless, interventions were carried out and a positive learning outcome resulted.

The results of the study are summarized in Table 1. In the study two sections of ED&G 100 participated yielding 16 four-person design teams. In Table 1, the first eight teams are from section 1, and the rest of the teams are from section 2. The column with the heading "Training" shows the values of the Boolean variable for each design team: teams receiving high performing team skills training were assigned a value of 1, and teams not receiving the training were assigned a value of 0. Average GPA denotes the average current grade point average of students in each design team. The grading scale is from 0 to 4, where 4 is the highest grade. Average contribution level is the average of peer ratings for overall contribution to the project within the design team. The scale used for this rating was between 1 and 10, with 10 being the highest contribution level. Overall project grade was calculated as explained in the performance evaluations section.

After enduring that the correlations between the independent variables "training", "average GPA" and the "average contribution level" were insignificant, the variables' effects on the overall project grade were investigated via a multiple linear regression study. There were two unusual data points in the data set: 6 and 7. For team 6, the project grade was unusually high, despite the fact that the team average GPA was lower and that in the overall data set the average GPA and the overall project grade had a positive correlation. On the other hand, despite a higher average GPA, team 7's overall project grade was unusually low.

Table 1: Intervention Results

Team Number	Training	Average GPA	Average Contribution Level	Overall Project Grade
1	1	2.713	9.650	73.20
2	0	3.505	9.938	96.85
3	1	2.870	10.000	79.40
4	1	3.372	9.160	92.40
5	0	3.185	9.975	95.90
6	1	2.203	9.325	91.00
7	0	3.027	9.900	79.00
8	0	3.330	9.700	80.00
9	1	2.625	9.750	82.39
10	1	3.237	9.837	91.92
11	0	3.210	9.950	87.49
12	1	2.938	8.575	85.07
13	0	3.345	9.350	94.51
14	1	3.402	9.900	93.51
15	0	3.158	9.962	88.86
16	0	3.210	10.000	91.40

When these two unusual observations were taken out of the data set, the remaining data yielded the analysis of variance results for the model Table 2 where the linear effects of training, average GPA and average contribution level on the dependent variable of the overall project grade are investigated. The partition of sum of squares of regression is given in Table 3.

Table 2: Analysis of Variance for the Multiple Linear Regression

Source	DF	SS	MS	F	P
Regression	3	501.81	167.27	9.67	0.003
Residual Error	10	173.01	17.30		
Total	13	674.82			

Table 3: Partition of Sum of Squares of Regression

Source	DF	SS
Training	1	93.19
Average GPA	1	407.34
Average Contribution Level	1	1.27

The mentioned model accounts for 74.4% of the total variation in the data. The effect of the training on the overall project grade is not significant in comparison to the effect of the team's average GPA. There may be several reasons for this finding such as the interventions may not have started early enough during the semester, or the length of the interventions may not have been adequate to completely

overcome the resistance encountered by those teams for being trained on high performing team skills. Nevertheless, two unusual data points for the model may be treated as signaling interactions beyond the effect of average GPA on the design team's performance, and hence a venue for further research. The first unusual data point was for team 6: This design team received the training and performed exceedingly well, despite the low level of the average team GPA. The second unusual data point was for team 7: This design team did not receive the training, and performed poorly its high average team GPA.

A similar analysis is done for the first half of the data (for section 1) as summarized in Table 3. In this case, only 19.3% of the total variation is accounted for. Also, it should be noted that although it is not statistically significant, the training variable seems to have a negative effect on the overall project grade for the teams in section1. This can be seen by the generated regression equation that is given below:

$$Y=185 -5.8 X1+4.3 X2-11.2 X3$$

where,

Y= Overall project grade of the design team,
X1= Training (Boolean),
X2= Average GPA of the design team, and
X3= Average contribution level within the design.

Table 3: Analysis of Variance for the Multiple Linear Regression for Section 1

Source	DF	SS	MS	F	P
Regression	3	111.0	37.0	0.32	0.812
Residual Error	4	463.1	115.8		
Total	7	574.1			

For section 2 a summary of the analysis of variance is shown in Table 4. This model captures the 86.5% of the total variation in the data set. Contrary to what is seen in the pervious equation, a positive effect of training on the overall project grade is observed, although it is not statistically significant. The regression equation for this set of data is:

$Y=36.1 +0.63X1+ 16.1X2 – 0.25X3$ for which the above definitions for Y, X1, X2 and X3 are valid.

Table 4: Analysis of Variance for the Multiple Linear Regression for Section 2

Source	DF	SS	MS	F	P
Regression	3	108.221	36.074	8.51	0.033
Residual Error	4	16.962	4.240		
Total	7	125.183			

The difference in the results for both sections may be the result of two major differences in two sections. The first difference between sections was that section 1 was not gender balanced. The class had only three women students out of 33. On the other hand, section 2 had 13 women students out of 32. Secondly, during the interventions, a strong resistance was encountered during the role playing intervention that was given to section 1. However, the resistance for the same intervention in section 2 was much lower.

If the differing performances of the two sections can be attributed to the differences in makeup and behavior of the two sections, it can be said that injecting high performance team skills into engineering design team curriculum seems probable. Certainly the investment is significant - - it takes a lot of time, effort, commitment, and resources. This significant investment, however, meets with anecdotal evidence in the form of unsolicited student responses on course critiques reinforces this view:

"Another aspect of the course we enjoyed was spending time with your (course instructor's) colleague discussing teamwork related issues. Utilizing the techniques such as AAR would have proven to be more useful if we would have done them earlier, i.e. the AAR evaluation process. We are still benefiting from these sessions, but they could have helped our project out significantly if we would have gotten the chance earlier in the semester."

CONCLUSION AND A NOTE ON THE FUTURE RESEARCH PLANS

It was proposed that the high performing team skills training and education could improve the performance of student design teams. Thus, after three two-hour interventions were given to one half sample of teams during an industry sponsored project, a study was undertaken to measure the effect of said training on design team performances. Although, the effect of the said training on the overall project grade, which was used to measure project performances, was not found to be significant; due to unsolicited student responses and the existence of data points revealing the importance of the training, furthering this research is found to be necessary.

The future research should include an increased dose of team related interventions throughout the semester which would be started earlier for teams which are formed taking into account the effect of team average GPA, gender and possibly adaptability of team members to change. Also, an investigation for an alternative methodology for allowing students to experience the stages of group development can be beneficial.

REFERENCE

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