2006-833: HOW THE PRESENCE OF WOMEN AFFECTS THE PERFORMANCE OF DESIGN TEAMS IN A PREDOMINATELY MALE ENVIRONMENT

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How the Presence of Women Affects the Performance of Design Teams in a Predominately Male Environment

Abstract

The literature reports conflicting results regarding the effect on team performance when one or two "minorities" are added to the team. Further, there are very few studies that report on teams that are actually doing engineering or design work, and even those studies normally define "performance" as the overall grade for the project rather than indicating how the teams performed on the various aspects of the design process. The current study presents results obtained for nearly 400 students working on 99 teams with a female minority of 14.1% working on a semester-long, sophomore, design projects. The team performances are compared in four categories: artifact testing, design critiques based on initial specifications, communications, and overall project grade. The teams with one or two females slightly outperformed the all-male teams in all categories but one. However, the increased performance is not statistically significant.

Introduction

There appear to be conflicting opinions related to the effect on a team's performance when a gender minority joins a team[1,2]. Some say homogeneous teams are more effective; some say heterogeneous teams are; and some say it doesn't matter. Many of the studies on the effect of gender on team performance are limited to cases in which the teams are performing non-engineering activities. In an exception, one study[3] concludes a team's gender composition to be an insignificant factor regarding the performance of product design teams. In another exception, a study[2] describes a design experience involving thirty-one females and sixty-five males assigned to twenty-three, four-person teams and one, five-person team in a course, Introduction to Engineering Design and Graphics. Teams were formed with comparable grade point averages or comparable scores on the mathematics portion of the SAT if grade point averages were not available. Two eight-week projects were conducted. Only one project required the testing of a design artifact, and its evaluation counted for 60% of the first project's grade. However, all teams scored between 100 and 110 on the testing; so it appears that team performances on the first project were discriminated primarily on the basis of the written reports (25%) (grades from 10 to 105) and the team quizzes (15%) (grades from 49 to 94). The second eight-week project was a paper study, and grading was based on team quizzes and a written report. In any event, the authors conclude that "the average performance of [gender] homogeneous teams is slightly better than that of heterogeneous teams." Their limited data indicted that nine all-male teams out performed three all-female teams by about 3%. The all-male teams outperformed the ten equally distributed teams (two males and two females) by 6% and two teams with one female each by 22%.

In a third study[4], team performances of freshman and sophomore students in an introductory design sequence were compared based on team makeup by gender. Teams were composed of from four to six members. Four team types were identified: all male (37 teams), male-dominated (more males than females) (39 teams), female-dominated (more females than males) (11 teams), and mixed (half males and half females) (8 teams). There were about twice as many freshman teams as sophomore teams. Females comprise about 25% of the student population, so all female teams were not feasible. Results are presented for each course and for the combined courses. The freshman course had a single project related to developing ways to transport lunar regolith (the fine particles covering the lunar surface) for processing; the sophomore teams chose from among 14 provided projects. However, it appears that none of projects required the fabricating and testing of a “design”. The only product of the projects was a final report which was graded using a rubric. It appears that at least 80% of the grading related to technical writing skills and not “design”. The remaining 20% was evaluated on the basis of the team’s ability to “develop and justify a feasible solution.” The grades for the freshman projects were essentially independent of team makeup for three of the four team categories (Overall grading and the grading of the “solution” portion varied by less than 2%.) while the teams in the fourth category, mixed, received significantly lower grades (nearly 20% lower) for both the overall grade and solution portion of the grade. In the sophomore course both the all-male teams and female-dominated teams showed significant improvement over their freshman class equivalents, 20% improvement for both overall and “solution” portion for the all-male teams and over 30% improvement for both overall and “solution” portion for the female-dominated teams. (However, these were apparently not the same students, as the studies of both courses seem to have taken place simultaneously.) The male- dominated sophomore teams actually scored slightly lower than the male-dominated freshman teams. There were no mixed teams in the sophomore course. As noted there was a total of only eleven female-dominated teams, five in the freshman class and six in the sophomore class. The method used to makeup the teams was not specified as there were multiple sections of each course, and the individual instructors made the decisions on forming teams.

The present study is presented in an attempt to address the issue of the effect on team performance of female presence on mostly male teams in the controlled environment of an engineering design class in which a design artifact is fabricated and tested. The vehicle selected was the design, fabricate, and test (compete), team design project that has been a requirement in our sophomore, Introduction to Design, course since 1980. The course is taught each fall and spring and averages about 45 students a semester. The project has represented between 40% and 50% of the course grade. Students self-select into teams of four (to the extent possible) and work for about ten weeks on these projects. The artifacts of the design process are evaluated through public testing and instructor evaluation. There is also a significant communications component. Further information on the course and typical projects is available[5-10]. The performances of teams from fall 2000 through fall 2004 are included in this study. The team performances in three aspects of the project: artifact testing, design quality, and communications as a function of the number of female team members are examined. Therefore the present study will represent improvements over the cited studies in that many more teams will be included and the evaluations of the teams will be in three different design related activities: the performance of the artifact (an important aspect of engineering design), the degree to which the artifact satisfies the specifications, and quality of the several types of written reports and an oral presentation.

The Projects and their Evaluation

The project begins in the first week of the class when the project description is distributed. Each student gives a five-minute "self-introduction" talk to the class, and class time is reserved for social contact among the students. In the third or fourth week the official, self-formed, teams are declared (although students may have been working together already). There are two "testing" components for the project which account for 35% of the project grade: an Initial Test with a reduced set of constraints about six weeks into the project and the Final Test in a public venue in which teams attempt to maximize a Figure of Merit. (Only the Final Test results are reported here.) The instructor evaluates the artifact itself according to a publicize rubric that attempts to evaluate the quality of the design in five categories based on the initial specifications:

- the creativity in selecting the concept (25%),
- the creativity in executing the concept (25%),
- the craftsmanship and the esthetics (20%),
- robustness and reliability (20%), and
- attention getting qualities (10%)

This evaluation accounts for 20% of the project grade. Finally 45% of the project grade is distributed among various communication requirements: two progress reports, a final report, an oral presentation and an extended abstract. Although the project itself changes each semester, these grading components have remained the same for nearly ten years.

The Fall 2005 project is typical and is summarized below (The actual instructions are usually an eight-page document.):

> Design, fabricate, and test an autonomous device that will separate as many as five golf balls and five ping pong balls, initially confined to a single (primary) container, by moving them into two separate (secondary) containers. The device will rest on a table provided by the instructor and the primary container will begin the process sitting directly on the table. There will be no external interference with the process once it is initiated. The balls must enter each secondary container in at least one second intervals (at least one second between "ball deposits"), and the entire process must be completed in less than 30 seconds. The device shall weigh less than seven pounds (the lighter the better) and shall fit within a cube, 30 inches on an edge before "deployment." Gravity activation is preferred but other actuation is allowed. No external power sources are allowed. There shall be two tests of the device: Initial Testing on October 3rd and Final Testing October 26th. The requirement for a successful Final Testing is to properly place at least two golf balls in one of the secondary containers and at least two ping pong balls in the other. The goal is to successfully place all five golf balls in one secondary container and all five ping pong balls in the other as fast as possible (but with at least a one-second interval between depositing the balls in each container) with as light a device as possible. Specifically, the goal is to maximize the Figure of Merit, FoM, defined as
>
> $$FoM = G + P + 0.5*G*P - |G-P| - 2*(N-G-P) + 4*(7-\mu) + 0.1*(30-\tau)(G+P)$$
>
> where
>
> N is the total number of balls initially in the primary container ($N \leq 10$),
>
> G is the number of golf balls successfully placed in the "golf ball" secondary container.

P is the number of ping pong balls successfully placed in the "ping pong ball" secondary container.
μ is the weight of the device in pounds ($\mu \leq 7.00$),
τ is the time for the run in seconds ($\tau \leq 30$)

Six examples solutions (from the sixteen produced) for fall 2005 are shown in Figs. 1 to 6 with the Figure of Merit (FoM) and the artifact evaluation both shown in each figure title with the scores reduced to a gpa: 4.0 = A, 3.0 = B, etc. Figures of Merit ranged from 1.68 to 4.48, and the artifact evaluations ranged from 0.87 to 3.93. The raw scores for the Figures of Merit ranged from 13.5 to 69.5 (The maximum practical Figure of Merit is about 70. Transport and separate all ten balls in about ten seconds with a 5-pound device.)

The Specifics

Grading records for the nine projects completed in the class from the fall 2000 through fall 2004 are summarized in Table 1. During this time period, 398 students working in 99 teams received a grade for the course and 14.1 per cent of the students were female. Eighty-seven teams had four members; seven had five members; and five had three members. As seen in the table most of the teams were all male (60). Twenty-four teams had one female member; thirteen teams had two female members; and two teams had three female members. The evaluation of various aspects of the team's performance is represented on a "grade point average" scale with an "A" equaling 4.0, a "B", 3.0, etc. in the four columns on the right. (Extraordinary work or performance is awarded a grade above 4.0.) As noted above, the project grade is composed of three components: artifact testing, design quality, and communications.

Some of the literature, e.g.[2], suggests that adding one female to an otherwise all male team could be disruptive. However, that doesn't seem to be reflected in the team performances in this study. Further, some say adding a second female would be better, while others say it would make things worse[1]. The current study indicates that adding females to the team, whether one or two, have

Fig. 1: Solution with gravity fulcrum lift, mechanical delay timer, and drop holes to separate. FoM = 2.86, artifact = 3.53.

Fig. 2: Solution with gravity torque lift, motor-driven rotating aperture timer, nearly parallel rods to separate. FoM=3.94; artifact=3.67.

Fig 3: Solution with spring lift, mechanical Delay, nearly parallel rods to separate. FoM=3.53; artifact =2.87.

Fig. 4: Solution with spring lift, gravity driven oscillating timers, nearly parallel rods to separate. FoM =4.48; artifact 3.93.

Fig. 5: Solution with spring lift, mechanical delay, hole sizes to separate. FoM=2.61; artifact 0.87.

Fig. 6: Solution with spring lift, mechanical delay, holes sizes to separate. FoM=1.68; artifact=3.0.

resulted in an increase in most performance areas (if we disregard the data for the two teams with three women each due to insufficient data). However, this increase is not statistically significant as can be seen in Fig. 1 in which all the team Project Grades are plotted against the number of women on the team. The correlation coefficient for a linear regression is less than 0.01, and these results are typical of the plots of the other grading components as well. The question then remains why do these teams do better when females are added.

Perhaps there are other issues involved which contribute to team performance besides gender. A previous study[11] looked at considerably more and different data but on fewer students (for the five sophomore design classes taught fall 2002 through fall 2004, i.e., a subset of this study). Data on 230 students working on 58 teams was collected. Their team performances are given in Table 2, and their demographic data and academic parameters have been compiled in Table 3.

Team performances in Table 2 mirror the results indicated in Table 1 in that team performance improves in each grading category when women join the teams. Peer evaluations (Autorating[12])

Table 1
Grading of Project Components by Team Make-up
(Nine Semesters, 398 Students on 99 Teams)

Number of Women on Team	Number of Teams	Avg. Team Size	Testing 25%*	Design 20% **	Comm. 45%***	Project Grade
0	60	4.00	**2.81**[a] 1.08[b] 0.34[c] 4.98[d]	**2.94** 0.92 0.86 4.57	**3.14** 0.63 0.65 4.10	**2.99** 0.65 1.48 4.05
1	24	4.12	**3.04** 0.92 1.14 4.59	**2.92** 0.82 1.28 4.28	**3.25** 0.56 2.17 4.12	**3.12** 0.56 2.03 4.09
2	13	3.92	**3.00** 1.29 0.91 5.14	**3.10** 0.66 1.26 3.88	**3.37** 0.51 2.37 3.93	**3.18** 0.62 2.15 3.98
3	2	4.00	**2.50** 1.17 1.33 3.66	**3.10** 0.02 3.08 3.12	**2.88** 0.40 2.48 3.27	**2.82** 0.56 2.26 3.38
Total or Average	99	4.02	**2.88**	**2.95**	**3.19**	**3.04**

*Final Testing
**Instructor Evaluation
***several written assignments and an oral presentation
[a] the average grade (4 = A; 3 = B; 2 = C; 1 = D; and 0 = F.)
[b] standard deviation of the grades
[c] lowest grade
[d] highest grade

were also conducted each semester, and the female students were rated an average of 6% higher than the male students (first row in Table 3). The female students held their own against the male students even though, on average, the male students were more than a year older and had seven months more engineering and general work experience. These particular measures are of interest since the previous study[11] (when gender was not considered) indicated that the better team players were older and had more work experience, especially engineering work experience. The females did have higher high school and college gpas and higher SAT Verbal scores, but again Reference 11 indicated that there is little if any correlation between good team players and any of these parameters. Therefore based on the demographic and academic data alone, there is no basis to indicate that the females would improve team performance as they have been shown to do. Similarly all the responses to the statements related to their satisfaction with the project and their team (Table 4) seem to indicate that the males are more satisfied with the course and perhaps better prepared. See statements 1, 3-6, 8-10.)

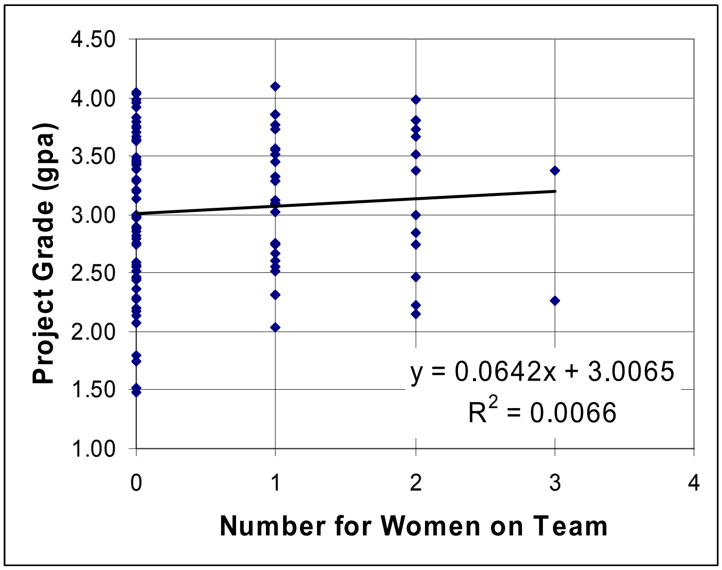

Figure 1: Project Grade versus Number of Women on a Team

Table 2
Grading of Project Components by Team Make-up for Five Semesters of Sophomore Design
(Fall 2002 through Fall 2004; 230 students, 18.7% female)

Number of Women on Team	Number of Teams	Testing 25%*	Design 20% **	Comm. 45%***	Project Grade
0	28	**2.95**[a] 1.12[b]	**2.84** 1.07	**2.90** 0.81	**2.91** 0.81
1	17	**3.09** 1.33	**2.98** 0.96	**3.28** 0.62	**3.16** 0.56
2	13	**3.02** 1.19	**2.97** 0.78	**3.52** 0.48	**3.25** 0.60

*Final Testing
**Instructor Evaluation
***several written assignments and an oral presentation
[a] the average grade (4 = A; 3 = B; 2 = C; 1 = D; and 0 = F.)
[b] standard deviation of the grades

Table 3
Demographic Data and Academic Parameters for Five Semesters of Sophomore Design
(Fall 2002 through Fall 2004; 230 students, 18.7% female)

	MALE		FEMALE	
	value	σ*	value	σ
Normalized Peer Evaluation	0.99	0.19	1.05	0.15
Age (years)	22.8	4.9	21.6	4.0
Work Exp (years)	4.8	4.2	4.1	4.1
Eng'g Work Exp (years)	1.1	2.8	0.4	0.9
College Exp (years)	2.5	1.3	2.3	1.0
High School gpa	3.4	0.5	3.7	0.3
SAT Verbal	547	100	580	80
SAT Analytical	650	75	650	75
U of Houston gpa	3.1	0.5	3.3	0.4

*Standard deviation

Discussion

This paper has presented data to indicate that female students seem to increase team performance marginally when added to predominately male teams. This increased performance is most clearly demonstrated in the improved communications component of the project but extends to a lesser extent to the successful testing and the increased quality of the artifacts themselves. None of the demographic, academic, work experience or preference data seems to predict this project

Table 4
Averages for Standard 5-Response Likert Scale Survey (5 = Strongly agree, 4 = agree, etc.) for Five Semesters of Sophomore Design
(Survey administrated at mid-semester.)

	M*	**σ****	**F*****	**σ**
I was looking forward to this class.	4.14	0.81	4.05	0.88
Learning to working in teams is important.	4.73	0.47	4.73	0.59
I like working in teams.	4.06	0.91	3.95	0.92
I am enjoying this class.	3.94	0.86	3.88	0.92
I like working with my team.	4.27	0.81	3.95	1.00
I would change teams if I could.	1.82	0.93	2.17	1.23
My team is working effectively.	3.97	0.88	3.88	1.09
I am a hands on person.	4.34	0.76	4.07	0.92
I have experience with hand tools.	3.99	1.08	2.85	1.22
I have experience in a machine shop.	3.17	1.36	2.88	1.70

* male responses
** standard deviation

***female responses
enhancement effect. Since data has been compiled over almost five years for this study there could some interest in whether grading standards were maintained and exactly when did these women participate in the project. Figure 2 depicts are the Project Grades over the nine-semester study, and Figure 3 plots the number of women in the class for each semester. There is slight grade inflation over the time period and a slight average increase in number of women in the class.

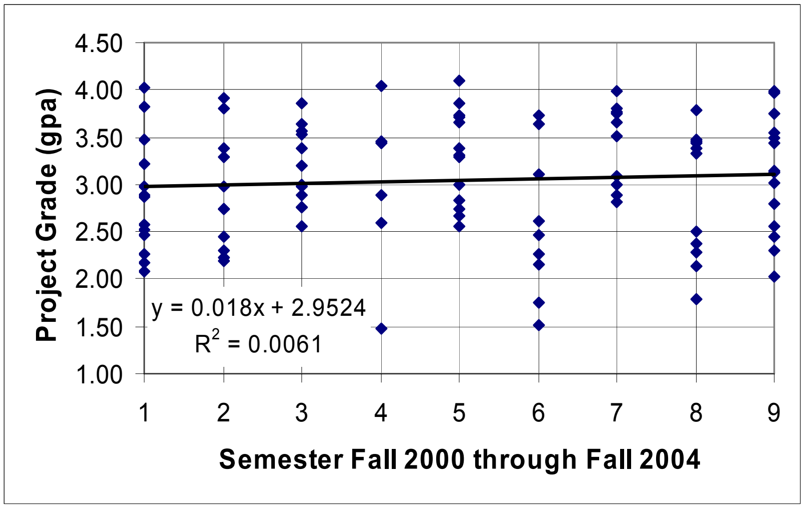

Figure 2: Project Grades over Nine Semesters

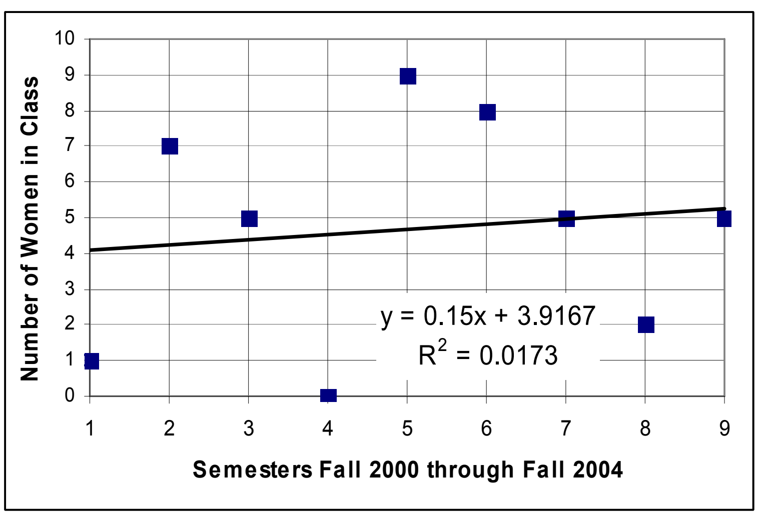

Figure 3: Number of Women in Each Class over Nine Semesters

Conclusions

As noted earlier, the literature has reported conflicting results regarding the effect on team performance when one or two "minorities" are added to the team. Further, there are very few studies that report on teams that are doing engineering or design work. The current study presents results obtained for nearly 400 students working on 99 teams with a female minority of 14.1%. The team performances were presented in four categories: artifact testing, design critiques based on initial specifications, communications, and overall project grade. The teams with one or two females slightly outperformed the all-male teams in all categories but one. However, the increased performance was not statistically significant. It is concluded that female engineering students make meaningful contributions to undergraduate engineering design teams, and they are at least as successful in this aspect of engineering as their male counterparts.

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