INTEGRATING PROCESS AND PRODUCT: IMPROVING ENGINEERINGEDUCATION THROUGH THE TEAM EXPERIENCE

Robert D. Knecht, Donna M Carlon
Colorado School of Mines/University of Central Oklahoma

Abstract – *This paper examines a teamwork model based on transport theory consisting of input/output conditions and external functions as an effective tool to assess performance of first-year engineering design teams. By comparing final attitudes with expectations, this study suggests factors that influence team decision-making processes. Key among these are the task and team-related roles assumed by the male and female members of the teams. An initial small sample study of six teams confirmed some of our expectations and expanded others. As expected, the male members of the teams concentrated on task functions. Female team members focused on both task and team functions, thereby providing a more integrated approach to the engineering design process. Because of the small sample size, we draw no conclusions. But these results point clearly to the need for expanded study of the teamwork model.*

Introduction and Overview of Our Study

The benefits of teamwork are widely recognized in both academic and industry environments. Research has shown that the success of student teams relies not only on the individual contributions of team members but in the *interactions* of team members and the roles that these members assume throughout the process[1]. High performing industry teams also demand both task and team orientations to insure successful outcomes[2]. But the literature diverges once these components are dissected. For instance, individual ability has long been thought to be key to successful outcomes. However, Bass[3] reported that the relationship between productivity and individual contributions was weak at best. It also appears that the impact of individual abilities declines as the interactive nature of the task increases[1,4,5]. The same is true for gender composition on teams. There is a virtually unlimited amount of research concerning the differences that women and men bring to the field of management; however, very little work has been done on differences in the team setting[6]. Since the fields of engineering and science increasingly demand the use of team decision-making in order to meet the needs of a rapidly developing technological society, it becomes necessary to examine the makeup of successful teams in the engineering environment. In particular, factors that affect team composition and team interactions appear to be crucial to successful outcomes.

Here at Colorado School of Mines we observed in the Design EPICS (Engineering Practices Introductory Course Sequence) Division that a significant majority of successful teams were mixed-gender teams. As an engineering school with an emphasis on technical studies, CSM is cognizant of the historical male-domination of the science and engineering professions[7,8,9]. Some research has shown that limited diversity enhances team performance, while no diversity or substantial diversity can actually hinder team performance[6]. Hence, in 1999 an interdisciplinary research team began studying the mixed-gender decision-making processes of student teams enrolled in EPICS. Once that was completed, a second phase focusing on gender composition and team interactions began. Reported here is a summary of the results of the first stage of our research project, conducted in the fall of 2000, along with detailed results of the second stage that was completed in spring 2001.

Background

The Design EPICS Program introduces students to an authentic design process addressing technical, open- ended, client-based projects. Mentors (experienced teachers) guide teams of students through the creative, interactive, and complex decision-making process. Teams absorb design process through practice, as they synthesize information, skills, and values. Project solutions are showcased at the end of the semester in written reports, oral presentations, and a graphics demonstration.

Our initial hypothesis came out of recognition of the value of women in decision-making, the value of women on teams, and the desire to develop a curriculum that promotes the attraction and retention of women in science and engineering professions. The historical basis for our hypothesis was drawn from documented research. Women's different perspectives on a broad range of social and political issues – from peace and war to domestic priorities – have influenced processes and outcomes within public-policy development and decision-making[10,11]. Women have contributed to educational research that has broadened healthcare, childcare, and welfare. Women in business management positions have brought more interpersonal process into decision-making activities and have placed more emphasis on discussion and consensus strategies[12]. Women do make unique contributions, and their lack of representation in the fields of science and engineering is detrimental to those fields.

Stage One: Gender-Based Contributions to the Team Process

Initially, our research looked at the individual contributions made by male and female students by using an observation protocol to examine task-related and team-related roles and functions. Our goal was to identify ways to attract and retain more women in engineering and engineering-related fields. Using Eberhardt's task and process instrument[13], trained graduate students observed approximately 300 first and second-year students enrolled in EPICS courses, comprising a total of 37 teams. The functions comprising the task function ranged from information giving and seeking to clarifying and summarizing. The process function focused on activities such as harmonizing, encouraging and compromising.

Thus our initial hypothesis arose from both observations of our own mixed-gender teams, and the relevant literature on leadership and team-based decision-making:

> We hypothesize that males and females bring different task and team functions to engineering design, functions which influence both the quality of the resultant product and the attitudes of the team members toward their team, work and product. We further hypothesize that males bring a focus on task functions and females bring a focus on functions that produce effective team management and leadership. Synthesis of these functions leads to successful problem solving, organization, and marketing of a project. Finally, we hypothesize that the success of a team requires a combination of both team and task functions.[14]

Therefore, initially we were mildly surprised to discover that there were no gender-based significant differences in task and process roles. We found no significant differences in the average proportion of male and female students observed displaying each of the five functions within the two roles[15]. Through further analysis, it became clear that overall composition and the pattern of interactions within the team was the key—not just gender. When the composition of the entire team was taken into account, both male and female students in male majority teams were more often observed clarifying and encouraging. There were no significant differences in any of the other eight functions.

The stage one research also included an analysis of the impact of team composition on overall satisfaction. A 15-item reflective survey assessed satisfaction at the end of the semester. Overall, satisfaction was slightly higher for all male and female majority teams, with female majority teams recording the highest levels. Both males and females reported greater satisfaction when they were in female majority teams, and lower levels of satisfaction in male majority teams. With these results in mind, we designed the second stage of the study, which is reported in detail below.

Stage 2: Research Questions

Because the results of stage one differed from much of the literature on leadership and gender-based decision-making, we sought to analyze the roles assumed by team members from several other perspectives to determine if other factors influence team function. Using a combination of self-administered surveys, student observations, and a scoring rubric, we sought to evaluate the relationship between the success of the team's efforts as influenced by expectations, attitudes, and roles. Success was defined as both quality of the output (product) and satisfaction levels of the team members. Thus, the specific research questions addressed in this stage were:

1. How does the gender mix of the teams affect satisfaction and quality?
2. How is team performance affected by attitudes in relation to expectations?
3. How do task and team functions differ among the male and female team members?

An Engineering Methodology for the Study

To answer our research questions, we began with a teamwork model proposed by Knecht[16] consisting of inputs and outputs as well as external factors (functions), which influence the performance of the team. Stewart, Manz, and Sims[17] agree that such a model can be a useful framework for addressing issues related to teamwork. This model, illustrated in Figure 1, depicts interactions that occur during solution of an open-ended engineering design project. We measured students' perceptions of their team experiences at the beginning (expectations) and end of the semester. Written design reports were used to gauge the quality of a team's proposed solution. We assessed team satisfaction with respect to events that took place during their experience. Product quality and team satisfaction defined success for the purposes of this study. By relating attitudes to team success and failure, this study is likely to suggest factors that influence team processes.

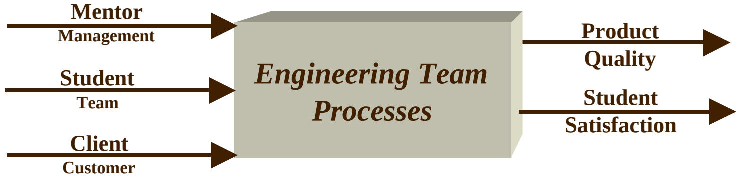

Figure 1: *Schematic Representation of Teamwork using an Engineering Format*

Our Sample

Because of the data-intensive nature of these research questions, the researchers determined that a small sample, representative of first-years students at CSM would be preferable for stage two. Therefore, two EPICS sections were chosen from the spring 2001 semester, with 22 male students and 11 female students agreeing to participate from seven teams. To determine team assignments, students were first asked to assess their own skill levels in areas such as writing, graphics, leadership, and computer literacy. Mentors then assigned students to the teams so that skill levels were equalized and so that as many teams as possible consisted of both males and females. Of the seven teams, one was all male, five were majority-male, and one was majority-female. Because the registrar's office at CSM randomly assigns students to class sections, the researchers believe that this sample adequately represents the population of first-year students entering the spring program (11.6 percent) and reasonably represents the first-year population (5.2 percent). Beyond this, the sample may not accurately represent the population of engineering student at CSM or at large.

Our Findings and Analysis

Data analysis is reported in three sections, corresponding to the research questions. In all instances, the SPSS statistical package was used to compile and analyze results.

Impact of Team Composition on Product Quality

The impact of team composition on product quality was observed by examining assigned scores on final reports. A scoring rubric developed and approved by experts in engineering education and writing assessment[18,19] was designed to evaluate written design reports. Kent and McGrath[20] presented findings to confirm that written products were an effective means to measure quality of solutions. An external reviewer assessed final reports from all teams participating in the studies. Based on the trend line shown in Figure 2, product quality tended to increase as the number of females on the team increased. Product quality of the all-male team was assessed at just under 8, while the majority-male average was over 9, and the majority female was almost 12.

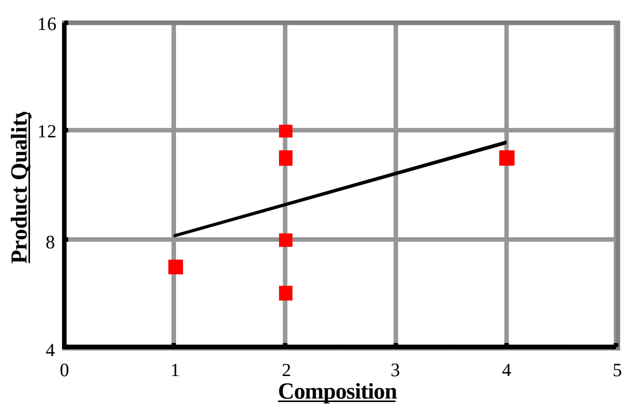

Figure 2: *Product Quality as a Function of Team Composition (1: all male, 2: majority-male, 3: equal distribution, 4:majority- female)*

Impact of Team Composition on Team Satisfaction

Another aspect of our team study was to consider the impact the composition of the team has on the satisfaction of the team members. A reflective (satisfaction) survey was administered at the end of the semester, designed to elicit from students their level of satisfaction with the engineering design experience. Students were asked to indicate on a four-point scale the extent to which they were satisfied with a series of described events. The scale ranged from extremely dissatisfied (coding of 1) to extremely satisfied (coding of 4). Responses that indicated that the student did not know (coding of 5) were treated statistically to be the same as a non-response. These results must be viewed with caution since a significant number of students (ranging from 25 percent to over 50 percent) responded "did not know" on all of the items.

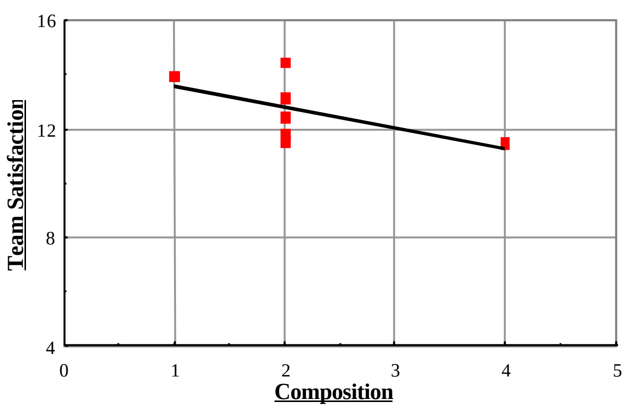

Figure 3: *Satisfaction as a Function of Team Composition (1: all male, 2: majority-male, 3: equal distribution, 4: majority-female)*

Using these data, we defined a single criterion to capture overall team satisfaction, similar to coefficients used to distinguish process equipment. Questions were arranged according to type: task, team, contribution, leadership and product. Data were averaged and normalized to coincide with the coding values. The five categories generated an overall value (15) consistent with the scale for product quality, a convenient but not necessary value. Overall team satisfaction decreased as the number of females increased on the team. The trend line, illustrated in Figure 3, corresponds to a linear representation of satisfaction. Team satisfaction averaged 12.7, varying by less than 5 percent with the average overall satisfaction value (13.2). First-year teams were relatively satisfied with the program, consistent with student comments about the program.

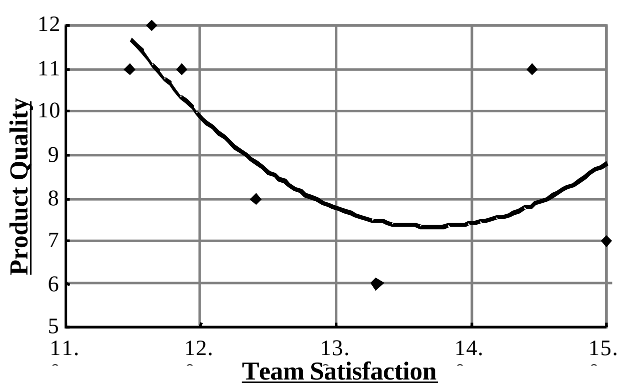

Figure 4: *Product Quality as a Function of Team Satisfaction*

Taking the analysis one step further, we examined the relationship between product quality and team satisfaction. We observed a potential relationship, illustrated by the trend line in Figure 4. Obviously as satisfaction was high, the team produced a high quality product. Not as obvious is the other extreme in which teams with low satisfaction also produced a high quality product. This trait is often associated with engineers expressing a need to produce a quality product to overcome the lack of satisfaction. If this relationship holds, we would expect a relatively uniform success characteristic for all teams

Students' Attitudes in Relation to Expectations

Data from the attitude survey indicate that these students began their engineering design experience with high expectations. Female students in general came into the project with higher expectations than the male students, illustrated in Figure 5. By the end of the project, female attitudes decreased whereas male attitudes increased. Agreement was strong and changes were relatively small. Three specific analyses established a focus on leadership/management and team interaction strategy for the teamwork component of the engineering design curriculum.

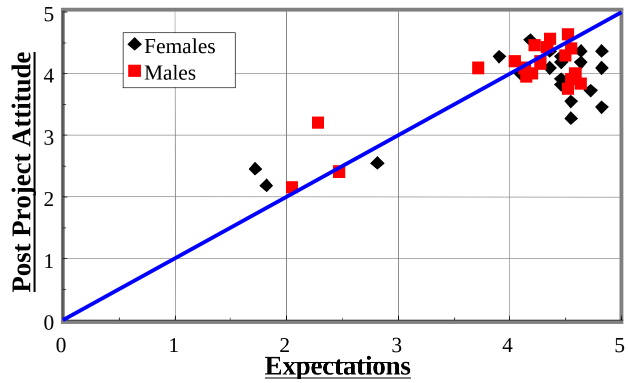

Figure 5: *Students' Attitudes Following Project in Relation to Expectations*

The first analysis of changes focused on changes in satisfaction between the beginning and the end of the project. Males were more satisfied with the leadership, (t = -3.01, 17 df, p=.0008) and management (t = -2.14, 18df, p = 0.046) at the end of the project. Females were less satisfied with team interactions (t = 3.73, 10df, p = 0.004) at the end of the project. Two strong, negative correlations surfaced in terms of satisfaction for females. These correlations existed with respect to female dissatisfaction with the direction the team was headed (R = -.63, p = 0.038) and how well the team defined and solved the problems it faced (R = -.72, p = 0.012). In summary we noted significant differences for both females and males with respect to project management and leadership and for females with respect to team interactions. As the project progressed, female satisfaction decreased while male satisfaction increased.

How do these findings relate to team performance? A positive correlation existed between team interactions and team performance for both females (R = .67, p = 0.024) and males (R = .72, p < 0.001) at the end of the project. A positive correlation between team leadership and team performance was also noted for the males (R = .59, p = 0.007) but not for the females. In summary leadership and team interaction contribute significantly to team performance.

Team Roles: Task and Team Functions Relating to Team-Gender Composition

A third emphasis of our study was to investigate the roles team members assumed throughout the project. Eberhardt[13] identified two sets of functions that are necessary to operate successfully as a team. Task functions, critical to product quality, focus on implementing tasks aimed at the overall team goal. Team functions, critical to team satisfaction, help teams to operate efficiently and effectively. Early in the semester, teams were asked to create a geometric figure out of a rope while blindfolded. Late in the semester, they were asked to build a tower out of blocks. During these teamwork exercises one team participated in the exercise while another team recorded observations of team and task functions that occurred during the exercise. Each observer recorded a tick for each occurrence of the function by a participant. We compiled the overall number and total number of ticks for each function and determined the percent occurrence of each function.

A larger number of task functions were recorded than team functions during exercise 1, illustrated in Figure 5. With respect to the task functions, males were observed initiating activities more than females, but females were observed summarizing. With respect to the team functions, females compromised more as the males engaged in more harmonizing activities. A very low percentage of observations were documented for standard setting. We might conclude that males attempted to lead the exercise by initiating and then trying to bring peace to the team. As the females would summarize the activities, they attempted to compromise to find a solution. Both males and females needed to engage in some standard setting in order to operate more effectively.

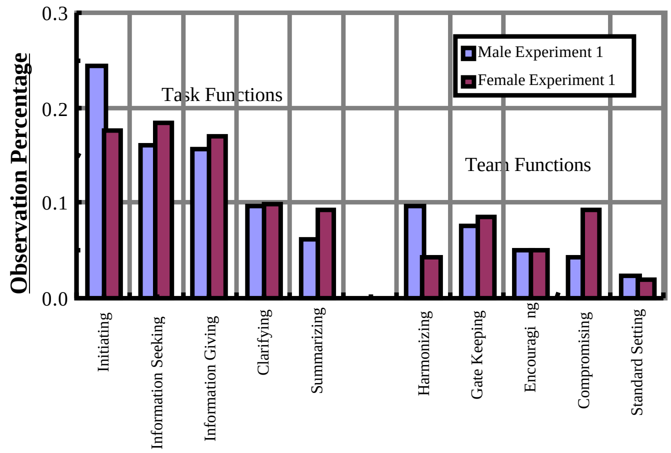

Figure 6: *Distribution of Task and Team Functions during Team Exercise 1*

The observations were distributed more evenly between the task and team functions during exercise 2. Males and females participated about equally in the majority of the functions, illustrated in Figure 6. Males were observed giving information more than females. Females, however, were more likely to seek and clarify information. Additionally, females more often encouraged the other team members, while males continue to harmonize and gate keep. By the end of the semester males continued to control the team with information giving and harmonizing, while the females continued to gather information, clarify and encourage.

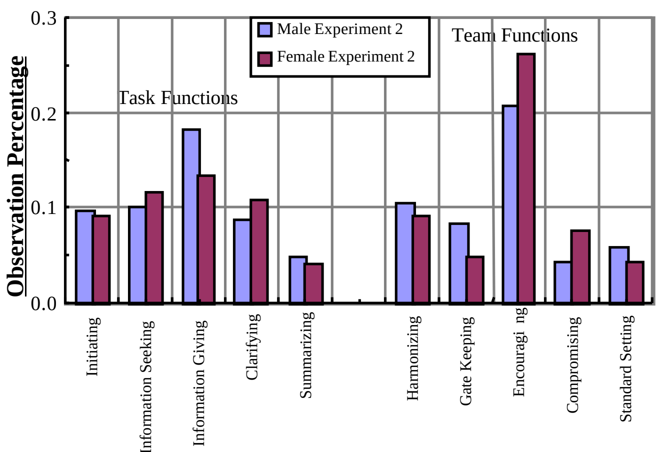

Figure 7: *Distribution of Task and Team Functions during Team Exercise 2*

Analysis of Task and Team Functions: Planning and Conflict

Two task activities caused significant differences in attitude for the entire class. Although students expressed high expectations that planning was an essential activity and that all members should participate actively in the process, they, especially males, expressed less agreement ($t = 2.98$, 30 df, $p = 0.006$) at the end of the project. Consequently, the entire class, especially males, expressed less agreement that decisions were made in a timely fashion with adequate opportunity for input and consideration by those affected ($t = 1.21$, 29 df, $p = 0.004$). Females expressed a strong negative concern ($R = -.64$, $p = 0.033$) that team energy was focused on one common strategy. By the end of the semester, males lowered their attitude that priorities were rapidly set within the team ($t = 2.36$, 19 df, $p = 0.029$).

Two team activities caused significant differences in attitudes following completion of the project. The entire class attitude decreased ($t = 3.32$, 30 df, $p = 0.003$) with respect to conflict being a normal part of working together and was dealt with openly and honestly. Complimenting this finding, we noted a significant decrease in attitudes ($t = 4.68$, 30 df, $p < 0.001$) in terms of the team providing a supportive environment for members to realize their uniqueness by allowing for and encouraging individual differences. Female attitudes negatively correlated to expectations in terms of the team skills at diagnosing and working on team problems and attend to process as well as content ($R = -.81$, $p = 0.002$). A similar correlation ($R = -.76$, $p = 0.007$) was also observed that team members feel responsibility for the success/failure of the team.

What have we learned from the Study?

Findings from stage two of this study provided a glimpse of factors that might influence the performance of first-year engineering design teams. Through this small sample study, we continue to identify potential differences between the impact of changes in team composition, product quality, and overall satisfaction. For instance, in stage two, we found that while first-year students began their engineering design experience with high expectations, females in general approached the project with higher expectations than the males. Product (report) quality averaged 14 percent higher than projections for first-year teams. For these six teams, product quality increased and team satisfaction decreased as teams went from all male to majority-female teams. The more satisfied teams produced lower quality products. The less satisfied teams produced high quality products to compensate for the lack of satisfaction. These findings agreed with those of Hanna and Wilson[21] who observe that too much cohesiveness likely lowers productivity but too little creates barriers to producing high quality outcomes.

Attitudes about leadership, management and team interaction differed between the 33 males and females on these teams. More males attempted to steer the team through functions such as initiating, information giving, and harmonizing. Although males were more satisfied with team leadership, more females were concerned about the direction the team was headed and that team energy was not focused on one common strategy. When these males were generally concerned about leadership and management of the team, they were less likely to produce a high quality product. The females sought to resolve project goals through integrating functions such as summarizing, clarifying and compromising. The females also offered encouragement to the team. These females, however, were less satisfied with team interactions, with the team's ability to diagnose and work on team problems and with the team's ability to attend to process as well as content. They expressed higher expectations that team members feel responsibility for the success/failure of the team. While these males placed greater importance on directing and managing project tasks, the females focused on team interactions. In summary, males and females in these six teams focused their attention on task functions required to implement the project, whereas females focused on the process as well as the content.

We observed that the synthesis of task and team functions led to successful engineering design, a similar observation reported by Applbaum[22] and Jones and Bearley[23]. Both female and male agreement declined in these six teams with respect to three activities that describe a combination of task activity and team interaction. First, project planning was an essential task activity and that all team members must participate actively in the process. Females were not satisfied with how well the teams define and solve problems. Second, decisions were made in a timely basis with adequate opportunity for consideration by those affected. Males were concerned that priorities were not rapidly set within the team. Third, both males and females expressed less agreement at the end of the project that conflict was considered a normal part of working together and should be dealt with openly and honestly. Teams needed to create a supportive environment to realize individual uniqueness by encouraging individual differences. These issues illustrated the integration of both a leadership/management component and a team interaction component. Our findings coincided with the premise that successful engineering design consisted of the synthesis of task and team functions.

Revising Our Hypothesis

In an effort to not lose sight of the individual and collective goals of this study, it becomes necessary to go back and look at them again. Have we been successful in addressing the questions that we initially asked? Are we heading toward our goals or away from them? Are we creating new and different goals generated by new data and new hypotheses? Our hypothesis has been modified to reflect the greater adaptability of females on engineering teams.

> We hypothesize that while the contributions of males on engineering teams more closely align with Eberhardt's task functions, the contributions of females on engineering teams are more likely to straddle task and team delineation, filling talent and team gaps as needed. We further hypothesize that a curriculum based on recognizing and cultivating these functions will encourage a higher quality team product and greater team satisfaction. In addition, we hypothesize that the proposed curriculum changes will ultimately promote a healthier environment for females in engineering and science fields in graduate study and later in industry. Our predication reflects the need for practical and immediate application of our findings.

How did we get there? By following our initial goals. We began by asking questions about the interactions of mixed gender teams. How could the teams be supported to promote a higher quality of product and the satisfaction of individual team members? How could the results of the investigation be used to improve team processes that take place in the classroom and in industry? As our research progressed, our emphasis changed. We asked more questions. Have we identified and evaluated research that examines the role of females in engineering and science? Have we recognized the value of females in decision-making, especially on teams? Can we identify and promote strategies that attract and retain these women?

We believe that we have presented evidence in this paper that answers a resounding "YES" to some of these questions. We have addressed our research questions regarding team gender composition as it relates to team expectations and satisfaction, quality of product, and team roles. We believe that the evidence we have collected will help us create a curriculum that supports and improves team processes.

We need to build on what we know, and further explore what we don't know. Although student participation was strong, more teams need to be involved in the research. We need to test our revised hypothesis with more teams in more educational settings. Studies need to focus on the more successful and less successful teams rather than studying average teams that tend to minimize differences. The design report rubric offers an excellent tool to assess product quality.

Observations of teams during teamwork exercises identify key functions that occur on teams involved with engineering design projects. This method needs to be conducted more frequently throughout the project in an attempt to better observe changes in team functions. The role that the mentor plays in team synthesis and productivity has yet to be analyzed. It is clear though that the Design (EPICS) program at CSM, as well as similar team-based curricula in other academic settings, can benefit from more research on improving teamwork processes to enhance leadership and management of the project and to encourage team interactions as the project progresses.

Bibliography

1. Bacon, D.R., Stewart, K.A. and Stewart-Belle, S., (1998) Exploring predictors of student team project performance. *Journal of Marketing Education,* 20(1): 63-71.
2. Larson, C. and LaFasto, F., (1989), Teamwork: What Must Go Right and What Can Go Wrong, Sage Publishers, London.
3. Bass,
4. Strong, J.T., and Anderson, R.E., (1990), Free-riding in group projects: Control mechanisms and preliminary data. *Journal of Marketing Education*, 12:61-67
5. Gentry, J.W., (1980), Group size and attitudes toward the simulation experience. *Simulation & Games* 11 (4): 451-59.
6. Baugh, S. G. and Graen, G.B., (1997), Effects of team gender and racial composition on perceptions of team performance in cross-functional teams. *Group & Organization Management* 22 (3): 366-384
7. Wilson, R. (1999), *An MIT Professor's Suspicion Leads to a New Movement for Academic Women*, Chronicle of Higher Education, Vol. XLVI, (15)
8. Parrot, L., (1998) Women and Culture of Engineering: Society Could Benefit from More Female Engineers. *Engineering and Technology for a Sustainable World, 5*
9. Fitzpatrick, J., (1999), Colorado Women in High Technology: Phase One Report, *unpublished manuscript, Graduate School of Public Affairs, U of CO., Women's Foundation of Colorado*
10. -----, (1992), Women in Politics and Decision-Making in the Late Twentieth Century: A United Nations Study, United Nations Office at Vienna, Centre for Social Development and Humanitarian Affairs, Norwell, MA: Kluwer Academic Publishers
11. Fraser-Abder, P., and Mehta, J. A., (1995), *Who benefits? Missing Links: Gender Equity in Science and Technology for Development/Gender Working Group, Ottawa: International Development Research Centre*
12. Powell, P., and Johnson, J., (1994), Gender and DSS Design: The Research Implications, *Decision Support Systems*
13. Eberhardt, L.Y., (1987), *Working with Women's Groups*, Vol. 1, Whole Person Association Inc, Duluth, Minnesota.
14. Thompson, D., Moskal, B. and Lasich, D., (1999), Engineering Design Teams: Influence of Gender Composition on the Decision-Making Process, *NSF Program Number: Grant 9979444*
15. Macdonell-Laeser, M.,, Moskal, B., Knecht, R. and Lasich, D., (2001),*The Engineering Process: Examining Male and Female Contributions*, 31st ASEE/IEEE Frontiers in Education Conference, Reno, NV.
16. Knecht, R. (1998), *An Engineering Approach to the Assessment of the First-Year Design Sequence at the Colorado School of Mines*, Proceedings of the American Society of Engineering Educators Conference, Seattle Washington.
17. Stewart, G.L., Manz, C.C., and Sims, H.P., (1999), Team Work and Group Dynamics, John Wiley and Sons, Inc., New York, New York
18. Leydens, J. and Thompson, D. (1997). Writing Rubrics Design (EPICS) I Internal Communication, *Design (EPICS) Program, Colorado School of Mines.*
19. Knecht, R. Moskal, B. & Pavelich, M. (2000). *The Design Report Rubric; Measuring and Tracking Growth through Success*. Paper presented at the ASEE Conference, St Louis, MS.
20, Kent, R.N. and McGrath, J.E., (1969), Task and group characteristics as factors influencing group performance, *Journal of Experimental Social Psychology*, 5, pp 429-440
21. Hanna, M. and Wilson, G., (1991), Communicating in Business and Professional Settings, New York, McGraw-Hill

22. Applbaum, R.L, (1992), Structure in group decision making. In Small Group Communication: A Reader, Edited by Cathcart, R.S. and Samovar, L.A., 6th edition, Wm. C. Publishers: Dubuque, IA
23. Jones, J.E. and W.L. Bearley, (1994), Group Development Assessment, HRDQ

Biographical Information

DONNA CARLON
Donna M Carlon, Ph.D., is assistant professor of business at the University of Central Oklahoma. Dr. Carlon's specialties are organizational communication and business research methods. She teaches both basic and advanced undergraduate and graduate classes in topics ranging from effective writing skills to leadership and organizational behavior.

ROBERT KNECHT
Robert Knecht's 25 years of experience in the industry focuses on technical and management support for minerals, energy and waste projects. He currently directs an engineering design program based on a curriculum that focuses on projects from industry. His projects require students to implement a design methodology in teams to resolve open-ended problems and to communicate both in written and verbal forms the results of their work.