AC 2008-1888: ACHIEVING TEAM WORK IN DESIGN PROJECTS: DEVELOPMENT AND RESULTS OF A SPREADSHEET TOOL

Rudolph Eggert, Boise State University

RUDY J. EGGERT is a Professor in the Department of Mechanical and Biomedical Engineering at Boise State University. His research interests include Engineering Design, Optimization, Design Theory and Methodology, Vehicle Design, Machine Design, and Probabilistic Analysis. In addition to conference papers and journal articles he authored Engineering Design, published by Prentice Hall in 2004.

Achieving Teamwork in Design Projects: Development and Preliminary Results of a Spreadsheet Tool

Abstract

Teamwork is instrumental for the success of many engineering design projects. Properly executed, outstanding teams utilize skills involving collaboration, communication, decision making, and self-management as they develop concepts, configurations, and detail designs.

Not all engineering students have or use teamwork skills, however. And it may not be their fault. In some cases, course instructors incorrectly assume that students have learned teamwork skills, and will automatically use them. In other cases, instructors provide a meager introduction to teamwork, but do not follow up. We can, and must, further improve students' teamwork skills by following up with appropriate feedback instruments, on a regular basis, such as mid-term and end of term peer and self-evaluations.

The paper discusses key elements of teamwork and how they relate to engineering design project teams. Then a spreadsheet tool and results of its use is presented. The tool requires each student to evaluate himself/herself and his/her teams mates covering 15 teamwork skills. The tool has been implemented over the last year and a half in the senior design project course and incorporates advanced spreadsheet features including hot-linked graphics, protected macros, student identification numbers, passwords, hidden rows and hidden sheets.

Introduction

As we participate on engineering design projects we learn to appreciate how rewarding, but yet, how difficult design projects can be. As suggested by Lewis[1] Starting with the project initiation, we often experience wild enthusiasm, fully excited about the challenges ahead. Later, a feeling of disillusionment usually sets-in as we realize the enormity of the work ahead. This sometimes leads to chaos among our co-workers to determine who should be doing what. Then senior management often begins to search for the guilty parties, leading to the punishment of the innocent and promotion of the non-participants, and finally the re-definition of the project requirements.

An engineering design project may be the most difficult assignment for an engineer, requiring the integrated and competent execution of:

1. engineering principles and practice,
2. design methods and procedures,
3. project management methods, and most important,
4. teamwork.

A *project* can be defined as a unique sequence of work tasks, undertaken once, to achieve a specific set of objectives.[2] Engineering design projects, in particular, focus on solving specific

design problems such as: fixing hazardous products, replacing environmentally toxic raw materials, improving functional features products and reducing overall manufacturing costs. Note that in a project we perform the work tasks only once. This helps to distinguish a project from daily work tasks. Baidu[2] lists principle elements of a project as: the *scope of work* which sets out the work tasks to be performed, the *budget* which estimates the cost for labor, materials and other resources to accomplish the scope of work, the *schedule* which estimates the completion date of each task, and the *quality* of the work performed. Well managed project teams use these elements to enhance their teamwork skills in communication, collaboration, decision-making and self-management.

A *team* can be defined as a group of people having complementary skills and knowledge that work together toward common goals and hold each other mutually accountable.[3] A product development team, for example, will have members from marketing, engineering design, purchasing, manufacturing engineering, production and distribution. The "team" shares the goal of developing a successful product. The team members also are mutually accountable for their fellow team members' performance.

Winning teams use teamwork! Many "teams," however, do not have *teamwork*. In professional sports, for example, we routinely witness examples where teamwork breaks down, as in missed calls, bad timing or inattention to the game. Winning sports teams and engineering design teams, however, usually exhibit strong teamwork skills.

While in college, an undergraduate engineer learns how to apply knowledge from mathematics and the physical sciences to the solution of text-book problems. Many degree programs include a succession of increasingly difficult courses in the engineering sciences which build competency in order to handle more complex, and in reality, more real-life problems.

Some institutions require semester-long courses in engineering design and or project management and or teamwork. And at many schools, the students participate on significant design projects during their senior year. At some schools, however, engineering design, project management and teamwork are combined in a single all-encompassing course.[4, 5, 6, 7] We might ask whether more emphasis should be placed on teamwork and teamwork skills development, considering industry's demand for these skills.[8,9]

This paper first compares teamwork in engineering design projects with teamwork in professional football as a means of characterizing common characteristics of teamwork . Then, necessary elements of teamwork and teamwork skills are proposed. And finally, we discuss a computer-aided teamwork evaluation tool and method along with preliminary comparative results.

Professional Football: An Example of "Winning" Teamwork

To identify some of the necessary ingredients of teamwork, let's consider a well-executed offensive play by a professional football team.

1. The coach gives the quarterback a signal to execute a "run" play in which the quarterback will hand-off the football to the halfback for a run up the middle.

2. During the huddle, the quarterback surveys the defensive lineup and spots an opportunity to run a pass-play instead, and tells the team about it.
3. The quarterback along with support form his team decides to execute a different "pass" play.
4. In a coordinated fashion, as the quarterback calls for the hike, individual team members perform separate roles, but with a common purpose of scoring.
5. Blockers protect the quarterback as he drops into the pocket for a pass.
6. A halfback sprints forward into a fake run.
7. As one receiver sprints from the scrimmage line he sees an opening and adapts his running pattern.
8. The quarterback lofts the football in his direction.
9. The receiver successfully catches the ball and heads toward the goal line.
10. His teammates move to block a path in front of him.
11. Using well-honed running skills, the receiver dodges the last tackler and scores a touchdown.
12. Now that was teamwork!

Let's examine some of the salient aspects of that winning play that are in common with teamwork including: communication, individual skills, team skills and risk management.

Communication
Winning coaches and players communicate during the game. Signals are carefully communicated so that every player knows the specific actions they are to take. As we have often seen in pro-football, games can be lost by players that "miss the call." Effective communication is similarly essential for an engineering design project. We all have to know what to do, when to do it and how to do it.

Individual Talent
Winning players are *good at the positions they play*. They prepare themselves in physical training such as weight-lifting, jogging, sprinting and other physical exercises, to develop individual abilities of speed and strength. They learn and memorize all the "plays" that the team may execute during a game. Similarly, successful employees recognize the importance of individual contributions and prepare themselves accordingly to work on a project team. Just like professional football players, they prepare by developing technical knowledge and skills in the basic sciences, mathematics, engineering sciences, manufacturing processes and design. They gain experience in design methods, computational tools, prototyping, and testing. They develop communication skills for effective listening, speaking, reading, interpreting, writing, sketching, and drawing. They learn and use the jargon of their discipline to enhance clear and concise communication. Lastly, they develop a professional interpersonal "style" embracing empathy, tolerance, honesty, trust, and personal integrity.

Teamwork
Winning teams use teamwork. They routinely practice offensive and defensive plays, so that they can flawlessly execute them during games. Individual actions get coordinated, creating choreographed, machine-like execution and timing. In fact, they practice to develop a repertoire of alternative plays to take advantage of situations, to adapt to new threats or opportunities.

Unlike a football team, a project team rarely gets the opportunity to "practice before the game!" Since many, if not most, engineering projects are unique each team will encounter new members, new situations, new work tasks, new schedules and new budgets. Project team members, therefore, usually develop both their individual, and teamwork, skills on-the-job, during each project. As a consequence, if a project is to be successful, we need to have outstanding employees that know and coordinate their roles and responsibilities. And that when the situation warrants they need to use adaptive business strategies and team-based decision making methods in order to resolve conflicts equitably and efficiently. And lastly they must be able to communicate well to establish clear and effective coordination.

Risks: Weather, Fumbles, Interceptions and Injuries

Football is filled with uncertainty such as weather changes, or player injuries, or simple mistakes such as fumbles or interceptions. Similarly, design projects have risk and uncertainty such as changes in scope of work, budget or schedule. Winning teams recognize that imperfect knowledge and risk are just part of the "game" and must be prepared for and managed, that decisions need to be made and actions need to be taken.

Elements of Winning Teamwork

Successful teamwork depends upon four major behaviors collaboration, communication, decision making, and self-management.[10]

Collaboration

Winning teams exhibit effective collaboration. They have members that are committed to the goals of the team, work cooperatively and constructively, actively participate in team activities, and support fellow team members. The quarterback, risked being sacked to make the throw and the receiver got blocking help from his teammates to make the touchdown. Similarly, during an engineering project we may have to undergo hardship, to give up a weekend of skiing, or a golf outing, in order to meet team work task delivery deadlines! Collaboration, in effect, requires subordination of our individual desires so that the team can benefit.

Communication

Communication is the means by which we exchange information between team members to coordinate team actions. Communicating involves both sending and receiving information. The quarterback communicated his observation to the offensive line thereby taking advantage of an opportunity. He also effectively communicated the timing of the hike, preventing an offside penalty. Downfield team members were watching and listening and came to aid of the receiver. The principle forms of communication include spoken and written messages. An effective communicator will spend time in preparing better written documents such as emails, memoranda, and reports, emails. And an effective communicator will take particular care to make himself or herself understood when speaking to teammates. Eggert[11] discusses listening skills as being just as important. Football players keep their "heads in the game" watching and listening, and

reacting as the play unfolds. Without "listening" the play might have ended differently. Winning project teams rarely miss opportunities because they communicate well to all stakeholders.

Decision making
Effective decision making begins with having a clear understanding of the problem. It also involves activities for generating, analyzing, evaluating and refining alternatives, and then implementing the best one in a timely fashion.

Team decision making takes more effort. It's quite different than when we make "individual" decisions. Because then we don't really need to communicate with, or understand, others. We can use our own criteria and selection process to decide the best alternative. We rarely have to compromise or consider other options if we don't want to. *Team decision making*, on the other hand, requires subordinating our own individual desires for the good of the team. For example, during the huddle, the team discussed alternatives and then *agreed* to commit its entire resources to the new play. Winning project teams need to gather pertinent data, established evaluation criteria, and importance weights. Then, develop team-based decision making tools such as a weighted rating evaluation to prioritize alternatives. Winning project teams often use *consensus decision making*, by thoughtfully examining all of the issues, and agreeing upon a course of action which does not compromise any strong convictions of a team member. Consensus decision making gives everyone an opportunity to present their case, while recognizing that in some circumstances a decision has to be made. While a team member may not get the choice he or she favors, at least he or she knows why, and moreover, agrees that the decision has to be made.

Self-management
Winning teams have members that manage themselves. In pro-ball, for example, players monitor and implement corrective physical training to keep in shape. They keep tabs on their game statistics, to look for improvements. In other words, effective team members monitor their own progress to meet established goals. They stay focused on important tasks. They use meeting time effectively and solicit constructive feedback on their performance, involve others in the entire decision making, and put top priority on getting results.

Measuring Teamwork
A set of 15 skills is proposed to help us measure each of these four broader elements of collaboration, communication, decision making and self-management. The 15 skills are written in a "positive response/attitude" fashion. In other words, if one responds yes to each of the items listed, he or she would be exhibiting good teamwork. There are no skills that a "yes" answer would indicate bad teamwork.

Each team member rates herself and also confidentially rates each other team member. Using an ordinal rating system, as shown in Table 2. It is used to indicate an approximate ability-level or proficiency-level for each skill. To receive a Teamwork Evaluation Rating average of 4.0, she would have to get 4's from everyone on the team for all 15 skills.

Table 1. Skills for improved teamwork.

Teamwork skills		
Collaboration	1.	Understands and commits to team goals
	2.	Participates actively in team activities
	3.	Respects individual viewpoints/differences
	4.	Accepts criticism
	5.	Assists other teammates
Communication	6.	Listens attentatively to others on team
	7.	Provides constructive feedback
	8.	Communicates clearly and concisely
Decision Making	9.	Makes decisions based on facts
	10.	Anticipates problems
	11.	Contributes to meetings
Self-Management	12.	Monitors self-progress
	13.	Completes individual tasks thoroughly
	14.	Completes individual tasks on time
	15.	Asks for help when needed

Table 2. Teamwork Evaluation Ratings.

Rating	Performance
4	always
3	frequently
2	sometimes
1	rarely
0	never

It appears rather simple. Have team members develop individual skills. Instill a spirit of collaboration. Establish effective communication systems. Deploy efficient team-based decision making methods. And lastly, encourage individual members to monitor their own progress. Theoretically yes, but in practicality it takes a lot of planning and execution to implement. The following section discusses how teamwork is integrated in its engineering program.

Sr. Design Project Teams

In the Mechanical and Biomedical Engineering Department at Boise State University, students are introduced to engineering design with some emphasis on teamwork beginning in a required freshman course (3 cr hr Introduction to Engineering). A full semester course in Design methods is required in the sophomore year which includes team-based design and build project (3 cr hr Mechanical Engineering Design). Note that the fundamentals of teamwork and project management are introduced at this time. In the senior year a course in Machine Design (3 cr hr) and another in Thermal/Fluid Systems Design (3 cr hr) are required. The Seniors are also required to take the two semester Sr. Design Project sequence (2 cr hr fall & 2 cr hr spring). Note that the students are grouped into teams and start their Sr. Design Projects the second week

of the fall semester. Since they have already learned design methods in the sophomore year, they "hit-the-pavement-running," needing only minor review sessions, lasting 10-15 minutes each.

The Sr. Design Project class meets two hours, twice a week for two semesters. The time is mostly used for team meetings, travel to clients, meetings with clients, CAD/CAE, prototyping, testing, and presentations. A small amount of time is used for min-review sessions, stand-up-and-deliver project reports (3 min each), and instructor meetings with each team. At this time brief reviews of team skills are presented (since they already learned them in the sophomore design course). The learning objectives for the two course sequence are presented in Table 3. Note that Teamwork is explicitly stated in objectives 2.3 and 2.4, but also implicitly in other learning objectives dealing with communication and relationships, for example. Teamwork is weighted as 30% of the final grade. The teamwork weighting has sufficient influence to "fail" a student for outright non-performance.

Table 3. Sr. Design Project learning objectives.

1. Design a component, system and or process:
   - 1.1. identify customer requirements & engineering characteristics
   - 1.2. recognize & articulate design constraints,
   - 1.3. identify relevant issues with respect to patents, legal liability, safety, and ethics,
   - 1.4. develop engineering design specifications,
   - 1.5. generate/synthesize alternative concepts, configurations and detail designs,
   - 1.6. analyze & evaluate alternative designs using a variety of methods,
   - 1.7. obtain & use appropriate product literature from vendors / suppliers,
   - 1.8. refine configuration, parametric and detail designs to meet specifications, and
   - 1.9. communicate design information verbally & graphically.

2. Manage group projects
   - 2.1. develop work scopes, schedules, and budgets,
   - 2.2. establish & use project control methods & documents,
   - 2.3. learn & apply effective team skills and concurrent engineering,
   - 2.4. establish & maintain positive working relationships with client(s), teammate(s), and
   - 2.5. communicate project performance verbally & graphically

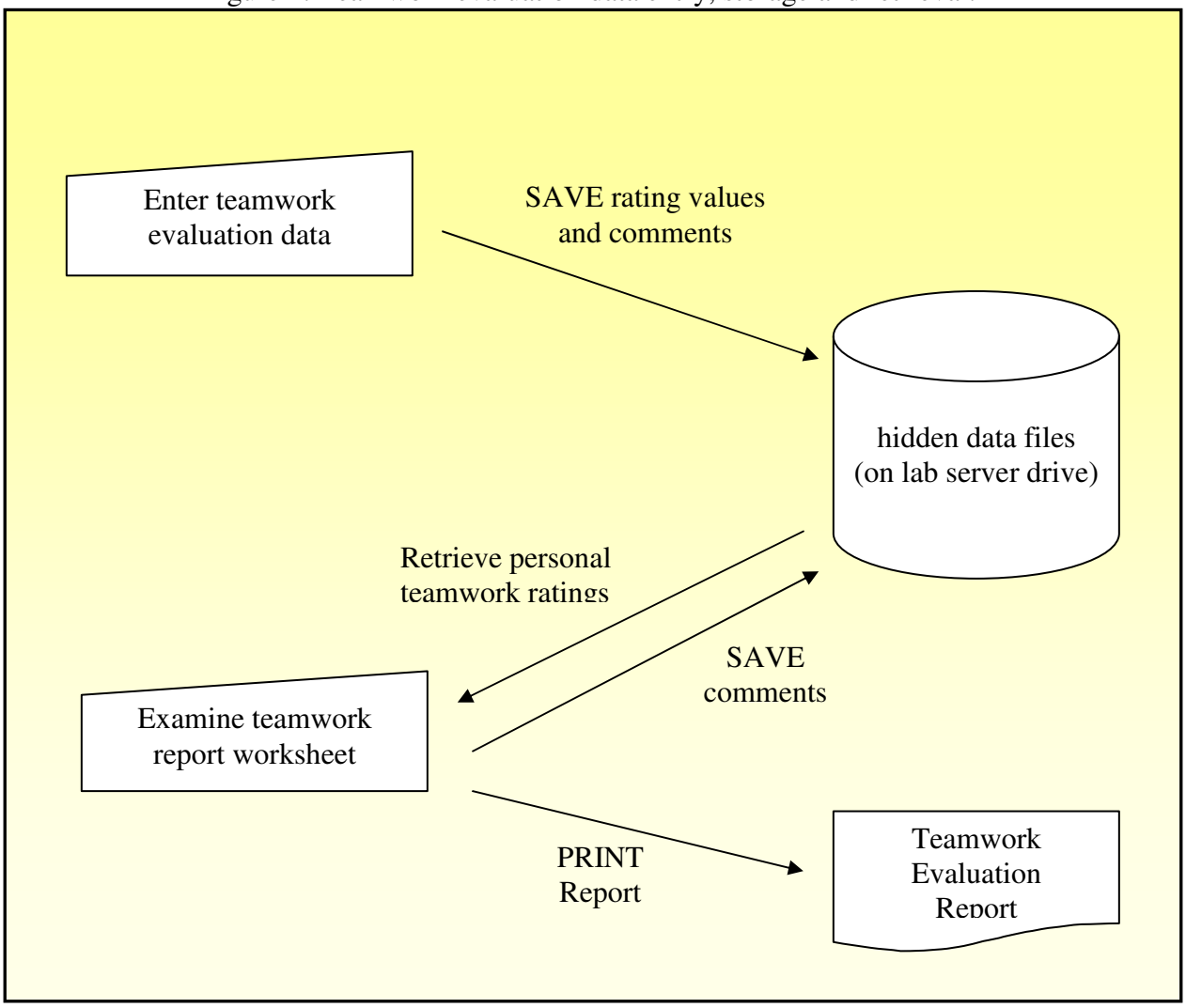
3. Integrate prior coursework & university resources:
   - 3.1. apply concepts, models, formulas and methods learned in prior courses,
   - 3.2. develop and conduct physical and/or numerical experiments, tests or simulations,
   - 3.3. implement available computer, laboratory and library resources,
   - 3.4. develop expertise relationships with faculty mentors, and
   - 3.5. communicate engineering information verbally & graphically.

Teamwork Evaluation System

A teamwork evaluation system, using an Excel spreadsheet, has been developed over the last year and a half in the Sr. Design sequence. Students evaluate themselves and their team mates at mid-semester and end-of-semester. The evaluations are confidential and automated.

The overall process is diagramed in Figure 1. Each team member uses a custom "pre-programmed" Excel workbook which stores individual data onto a common server drive. When all the team members have submitted their ratings, they can examine their own averages to see how other team members rated their teamwork skills. Each member is asked to reflect on his or her progress and to suggest ways to improve his or her rating during the next rating period.

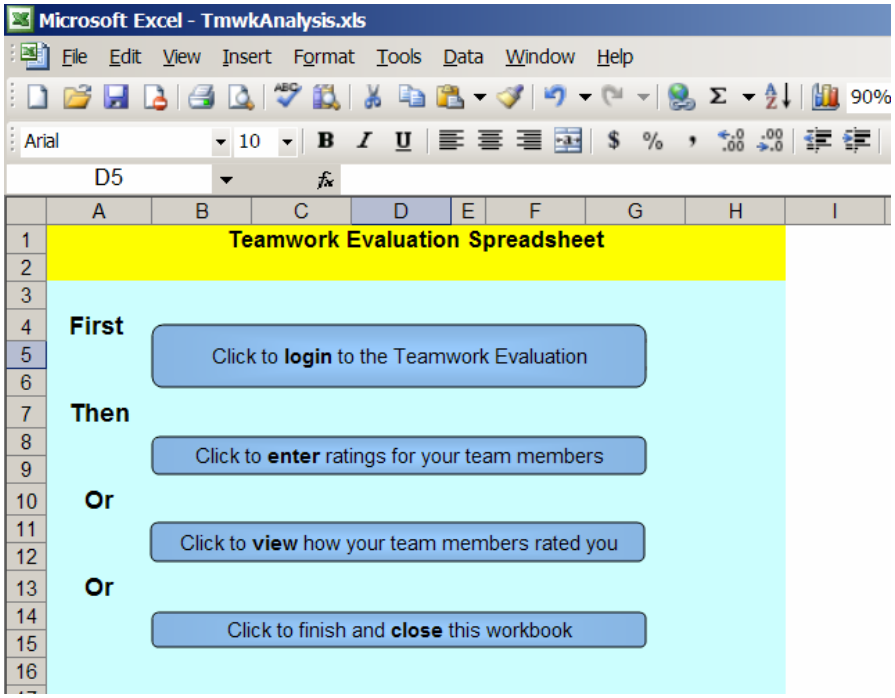
Figure 1. Teamwork evaluation data entry, storage and retrieval.



Part A: Data Entry: Team members enter evaluation ratings and save to data files.

1. Student logs on to computer in campus lab.
2. Student executes TEAMWORK.xls workbook. This brings up the top level hot-button sheet as shown in Figure 2 below
3. Student clicks on the log-in hot-button. This brings up a dialog box for the student to enter his last name and id number (i.e. log-on). If the name and id number agree, the student proceeds. If not, the student is asked again to re-enter his name and Id number.
4. Student clicks hot-button which displays (un-hides) the Teamwork Evaluation worksheet as shown in Figure 3.
5. Student then enters ratings (i.e. integers between 0 and 4) for herself and her team members.
6. Student saves ratings onto hidden data file by clicking "SAVE" hot-button. Note that the ratings and comments are anonymous. They are not shared with the other students. Only the instructor has access.
7. Student logs-off or closes the workbook

Figure 2. Top-level worksheet to automate data entry and retrieval.



Part B: Self-evaluation: When all members of the same team have completed their evaluations. The program will not display results until all members have submitted their ratings. This helps to preserve anonymity.

1. Student logs on to computer in campus lab.
2. Student executes TEAMWORK.xls workbook. This brings up the top level hot-button sheet as shown in Figure 1.
3. Student clicks on the log-in hot-button. This brings up a dialog box for the student to enter his last name and id number (i.e. log-on).If the name and id number agree, the student proceeds. If not, the student is asked again to re-enter his name and Id number.

4. Student clicks on the hot-button to display a hidden Teamwork Evaluation Report as shown in Figure 4. Note that for each of the 15 skills, the frequency of responses is calculated. In addition the numerical average of the ratings is shown. Also note, that the student's own rating is excluded from the calculation of the average, so as to offset any bias it could create.
5. The student is asked to reflect on why her averages are higher or lower than how the team rated her, and to comment on how might she improve her teamwork during the next review period.
6. Student clicks on the "PRINT to save report" hot-button which saves her comments onto hidden data file and prints out a hard copy.
7. The student looks over the report for accuracy and turn-in the report to the instructor.
8. The instructor reads the comments and writes his own comments on the bottom of the report, either reinforcing or constructively disagreeing with what the student commented.
9. The instructor hands back the Teamwork Evaluation Reports to the students.

Figure 3. Worksheet to enter and store teamwork evaluation ratings.

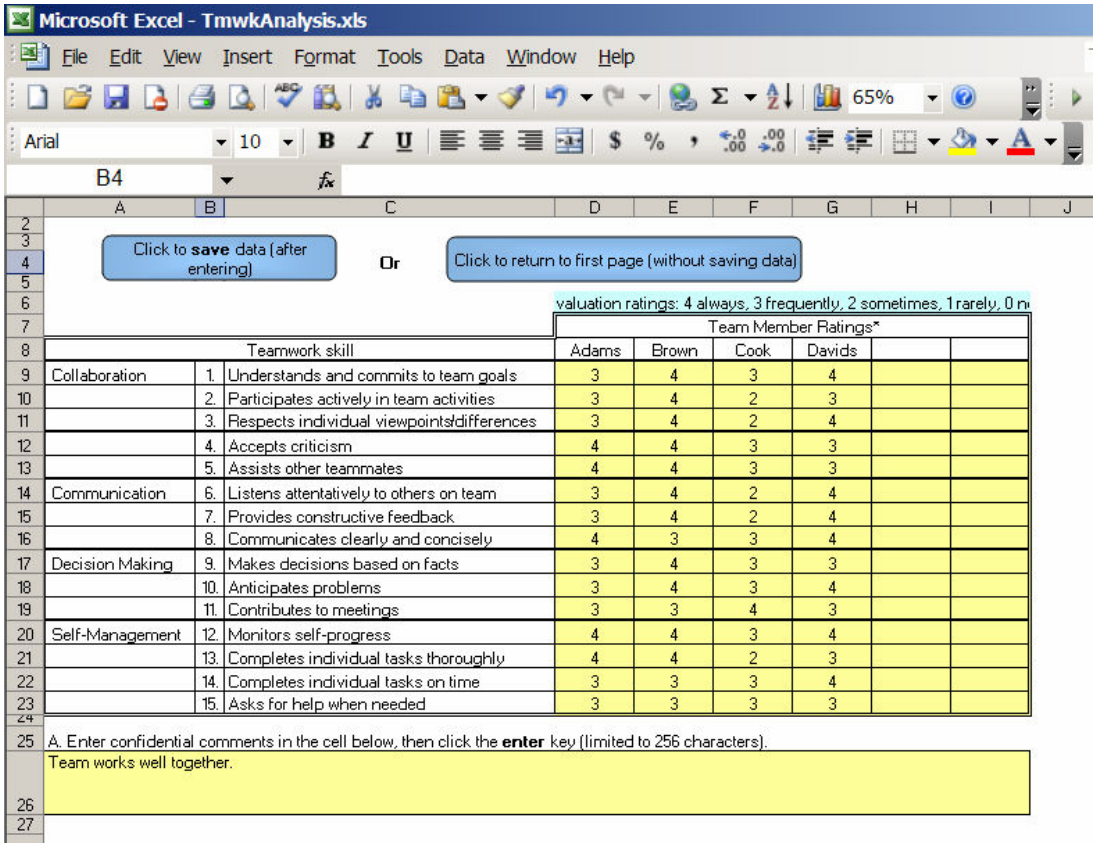
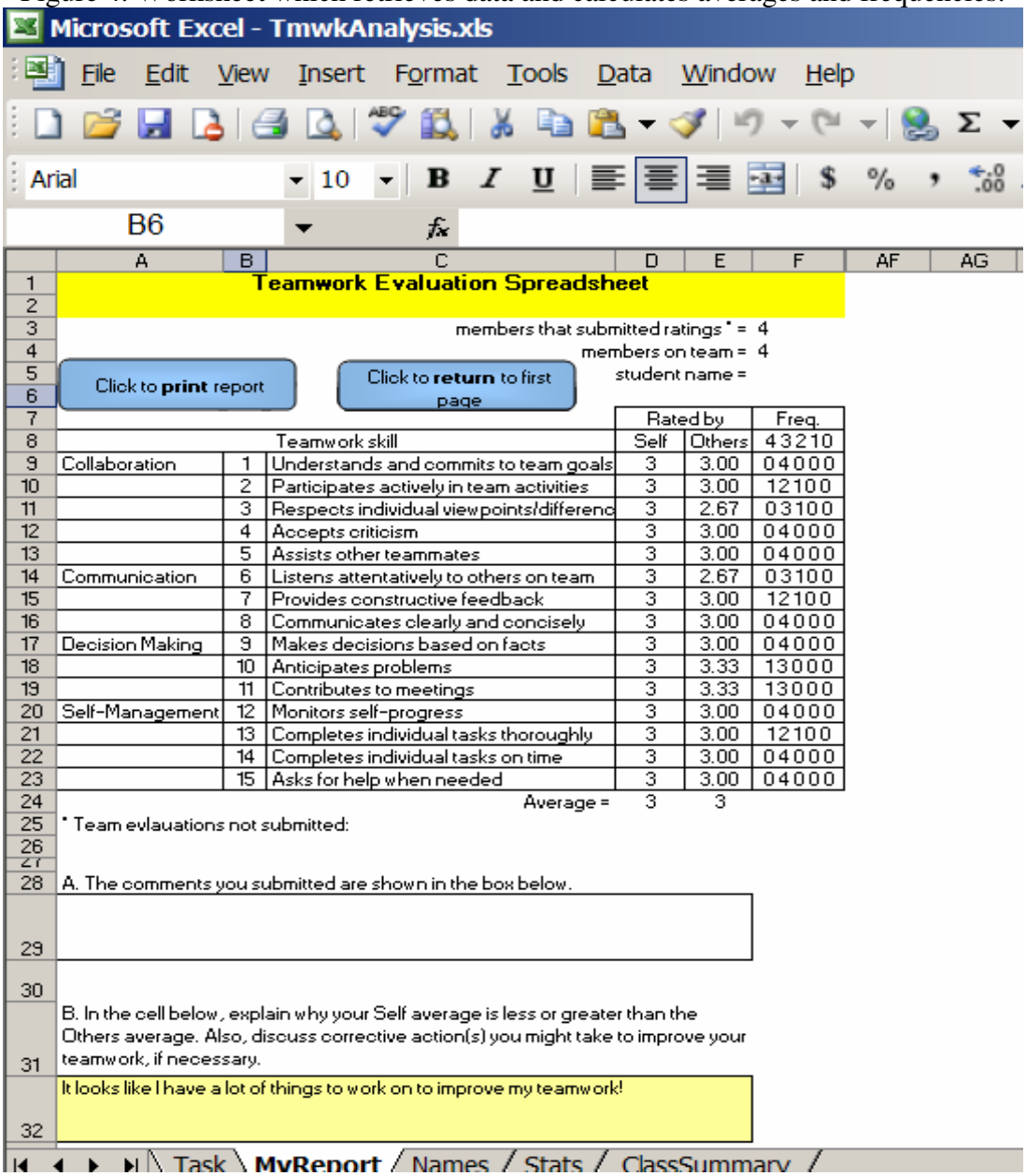


Figure 4. Worksheet which retrieves data and calculates averages and frequencies.



Microsoft Excel - TmwkAnalysis.xls

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B6

Teamwork Evaluation Spreadsheet

members that submitted ratings * = 4
members on team = 4
student name =

Click to **print** report | Click to **return** to first page

			Teamwork skill	Rated by Self	Rated by Others	Freq. 43210
9	Collaboration	1	Understands and commits to team goals	3	3.00	04000
10		2	Participates actively in team activities	3	3.00	12100
11		3	Respects individual viewpoints/differenc	3	2.67	03100
12		4	Accepts criticism	3	3.00	04000
13		5	Assists other teammates	3	3.00	04000
14	Communication	6	Listens attentatively to others on team	3	2.67	03100
15		7	Provides constructive feedback	3	3.00	12100
16		8	Communicates clearly and concisely	3	3.00	04000
17	Decision Making	9	Makes decisions based on facts	3	3.00	04000
18		10	Anticipates problems	3	3.33	13000
19		11	Contributes to meetings	3	3.33	13000
20	Self-Management	12	Monitors self-progress	3	3.00	04000
21		13	Completes individual tasks thoroughly	3	3.00	12100
22		14	Completes individual tasks on time	3	3.00	04000
23		15	Asks for help when needed	3	3.00	04000
24			Average =	3	3	

* Team evlauations not submitted:

A. The comments you submitted are shown in the box below.

B. In the cell below, explain why your Self average is less or greater than the Others average. Also, discuss corrective action(s) you might take to improve your teamwork, if necessary.

It looks like I have a lot of things to work on to improve my teamwork!

Task | MyReport | Names | Stats | ClassSummary

At the end of the end of semester the instructor examines each team member's rating report and compares it to the prior period to see if there was any improvement for each of the 15 skills and the overall average. The instructor writes further comments and or suggestions on the submitted hard-copy and returns to team member.

Theoretically, by using this feedback system, we should expect see some improvement between first and second reports. Improvements can occur due to improved ratings on specific skills or an increase in the overall average rating or both.

Improving Teamwork: Preliminary Results

Data from a class of 29 Sr. Design Project students were analyzed for the 2007 fall semester. Note that the Sr. Design Project course is a fall and spring semester sequence. The results from the spring semester will be presented in a second paper.

We should expect to see some improvement in most student's teamwork ratings between the mid-semester evaluation and the end-of-semester evaluation. Similarly we would expect to see some improvement, for the class as a whole, in each of the 15 skills.

An overall teamwork evaluation rating (TER) for each student is calculated by computing the simple arithmetic average of the 15 skill ratings. Note, therefore that each TER average equally weights the 15 skills. The student's overall average is shown on the bottom of his or her "Report" as shown on Figure 4.

To examine whether the class as a whole improved or not, we calculated the simple average of the 29 student TERs, which is shown in Table 4 below. Recall that each student rates himself and each of his teammates. The Self columns indicate that the students felt that they improved their overall teamwork by 0.01 rating points from the mid-semester to the end-of-semester. The standard deviation of the averages decreased from the mid-semester to the end of the semester. This might be expected as one "zeros" in on a target's bull's-eye as time progresses. This is much like a cruise control that recovers to the set-point speed when climbing a hill.

Table 4. Overall average of 29 students' teamwork evaluation ratings.

	Self			Others		
	Mid Sem	End Sem	Change	Mid Sem	End Sem	Change
Avg TER	3.60	3.61	0.01	3.69	3.66	-0.03
St. Dev.	0.263	0.258	-0.005	0.192	0.185	-0.007

It is interesting to note however, that as students were rated by their teammates (i.e. "others"), their average ratings indicate a decrease in teamwork by 0.03 points. There is a decrease in standard deviation (as with the Self ratings). The changes are quite small and statistically insignificant. Therefore it is difficult to conclude whether there was improvement in the overall average teamwork of the class.

Another way of examining the class as a whole, was to classify the 29 students' TERs (i.e., overall teamwork ratings) into three groups. Table 5 below shows the number of students whose overall average increased, stayed the same or decreased. We see under the Self column that 41.4% of the students thought their teamwork skills got better, and 55.2 % got worse over the semester. When rated by their teammates, it appears that only 31 % of the students actually improved while 55.2 % of the students got worse.

Table 5. Number of students whose overall teamwork average increased, decreased or stayed the same (i.e. from mid-semester to end-of-semester).

	Self		Others	
	No.	%	No.	%
Increased average	12	41.4	9	31.0
No change in average	1	3.4	4	13.8
Decreased average	16	55.2	16	55.2
Total	29	100.0	29	100.0

As suggested by Tuckman[12] project teams often experience four stages: forming, storming, norming, and performing . During the *Forming* stage members politely interact to learn about the nature of the tasks to be performed, the goals of the project, and the personalities and work styles of fellow members. During *Storming*, members begin to realize the enormity of the project and recognize differences in individual abilities, personalities, and work styles. Disagreement and conflict often lead some members to retreat from the group and others to try and "do it alone." Tension, conflict and scape-goating often occur. During *Norming* members begin to cooperate with each other. They begin to understand and respect individual strengths and weaknesses. They begin to focus on common goals and communicate more openly. They evolve acceptable standards of behavior or norms for performing their roles and resolving conflict. And slowly a team spirit begins to emerge. And lastly, during *Performing* the team is productive and satisfaction is high. They share accountability for their actions are strongly united. Project activities are conducted in an atmosphere of trust and mutual support. Conflicts are resolved openly and effectively as members are comfortable with their roles.

One possible explanation for the apparent lack of "significant" improvement may be that the team members are somewhere in the middle of the Form, Storm, Norm and Perform stages in their project. As each project progresses, students become more familiar with the teamwork skills, the rating numbers and how to rate themselves and each other. On other words, perhaps they have learned to be more critical of themselves and each other during the semester. Since they have one more semester to work on their projects we would expect to see some normalizing of evaluation ratings and hopefully more improvement in teamwork ratings during the spring semester.

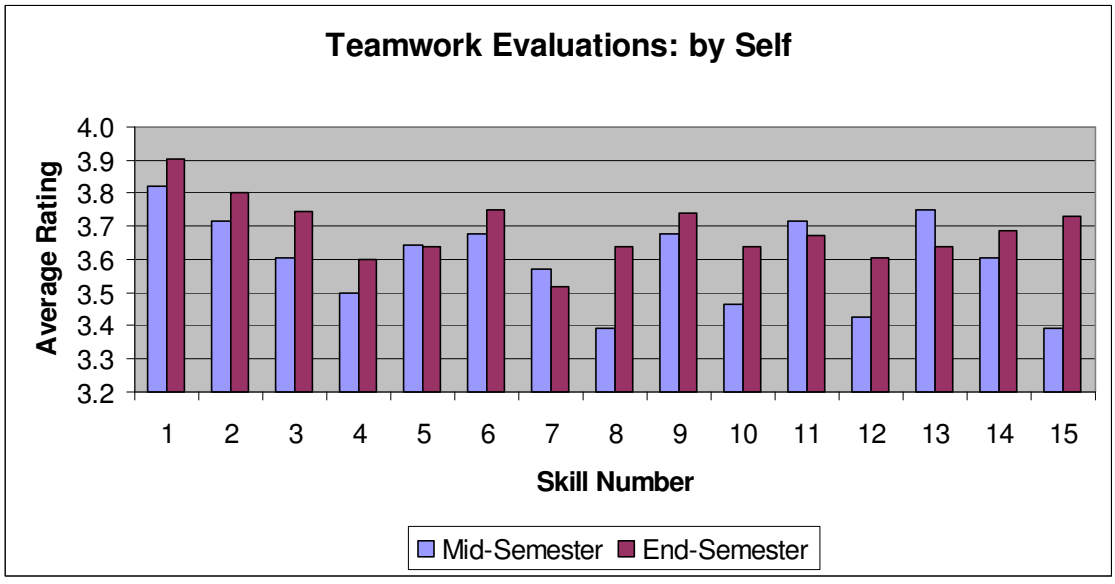
We next examine whether any specific teamwork skills standout as having been improved or not. Table 6 below shows the average of 29 students' self ratings for each team skill. For example, we find that the average rating of 29 students for skill no. 1, (i.e. understands and commits to team goals) improved during the semester. In other words, the average student felt that she made an improvement for that skill. There were 11 skill improvements and 4 skill declines. It appears that when evaluating themselves the students generally thought that their skills got somewhat better. The data are illustrated in Figure 5 below.

When examining the amount of change that occurred during the semester we see that the average student felt that they made much improvement in skills #3, 8, 10 12, and 15 (shown as shaded).

Table 6. Average self-rating of each skill by 29 students.

No.	Skill	Mid Sem	End Sem	Change
1	Understands and commits to team goals	3.82	3.90	0.08
2	Participates actively in team activities	3.71	3.80	0.09
3	Respects individual viewpoints/differences	3.61	3.74	0.14
4	Accepts criticism	3.50	3.60	0.10
5	Assists other teammates	3.64	3.64	-0.01
6	Listens attentatively to others on team	3.68	3.75	0.07
7	Provides constructive feedback	3.57	3.52	-0.05
8	Communicates clearly and concisely	3.39	3.64	0.24
9	Makes decisions based on facts	3.68	3.74	0.06
10	Anticipates problems	3.46	3.64	0.17
11	Contributes to meetings	3.71	3.67	-0.04
12	Monitors self-progress	3.43	3.61	0.18
13	Completes individual tasks thoroughly	3.75	3.64	-0.11
14	Completes individual tasks on time	3.61	3.68	0.08
15	Asks for help when needed	3.39	3.73	0.34

Figure 5. Average of 29 students self ratings for each teamwork skill.



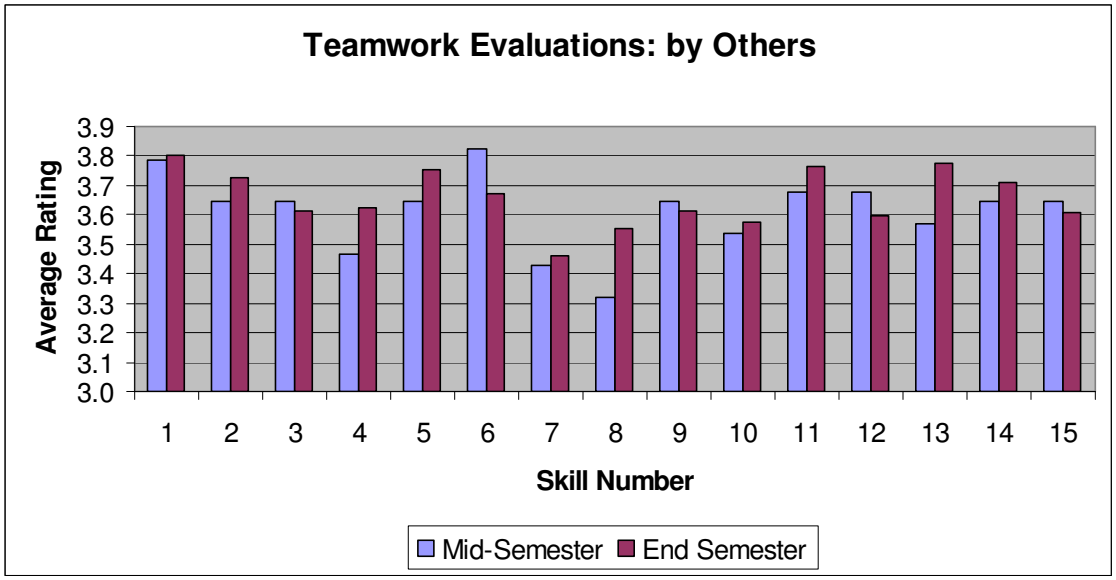
While it is important to assess how we think we improved, it is perhaps more important to the team as to how the team felt about our teamwork skills. Table 7 below shows the average of 29 students' others ratings for each team skill. For example, we find that the average rating of 29 students for skill no. 1, (i.e. understands and commits to team goals) slightly improved during the semester. It appears that the "others" on our teams assessed our teamwork as having improvements in 10 skills and declines in 5 skills. The data are illustrated in Figure 6 below.

When examining the amount of change that occurred during the semester we see that the others on the teams felt that the average student made major improvement in skills # 4, 8, and 13 (shown as shaded). Note that both the self and the others agree on only skill # 8 (Communicates clearly and concisely).

Table 7. Average others ratings of each skill by 29 students.

No.	Skill	Mid Sem	End Sem	Others Dif
1	Understands and commits to team goals	3.79	3.80	0.02
2	Participates actively in team activities	3.64	3.73	0.08
3	Respects individual viewpoints/differences	3.64	3.61	-0.03
4	Accepts criticism	3.46	3.63	0.16
5	Assists other teammates	3.64	3.76	0.11
6	Listens attentatively to others on team	3.82	3.67	-0.15
7	Provides constructive feedback	3.43	3.46	0.03
8	Communicates clearly and concisely	3.32	3.55	0.23
9	Makes decisions based on facts	3.64	3.61	-0.03
10	Anticipates problems	3.54	3.58	0.04
11	Contributes to meetings	3.68	3.76	0.08
12	Monitors self-progress	3.68	3.60	-0.08
13	Completes individual tasks thoroughly	3.57	3.77	0.20
14	Completes individual tasks on time	3.64	3.71	0.07
15	Asks for help when needed	3.64	3.61	-0.04

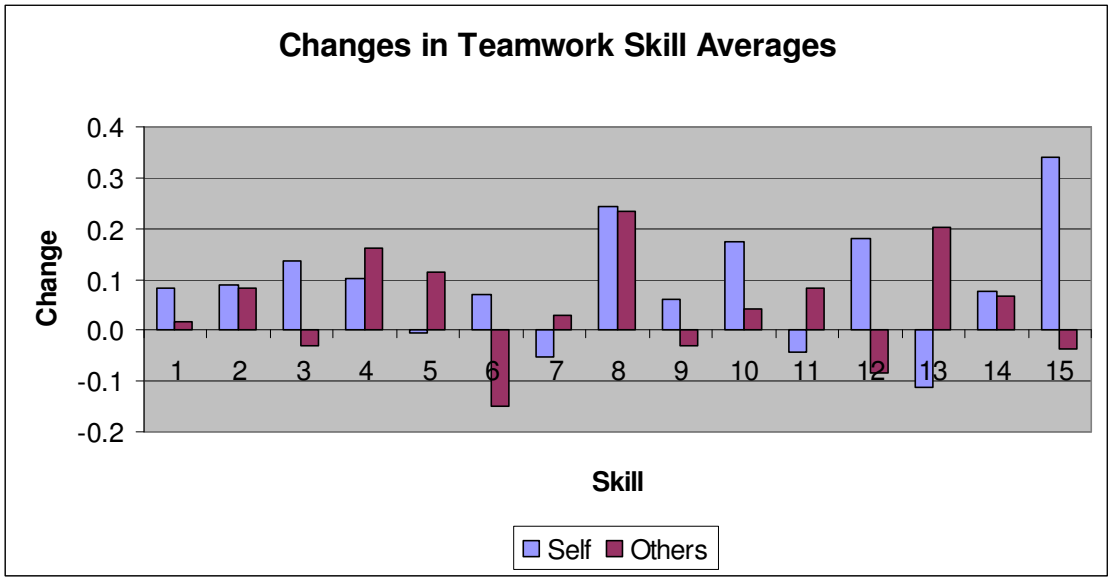
Figure 6. Average of 29 students others-ratings for each teamwork skill.



Plotting the change columns from tables 6 and 7, we can get a slightly different illustration of whether there any improvements in teamwork skills as shown in Figure 7. The left bar illustrates the improvements and or declines in how students evaluated themselves. The right bar, indicates

how the "others" on the team evaluated them. For the most part, the students thought that they improved in 11 of the 15 skills except #5, 7, 11 and 13. Others on their teams generally agreed that there was improvement in 10 of the 15 skills, except for #3, 6, 9, 12 and 15.

Figure 7. Teamwork skill ratings changes during semester.



Perhaps the most interesting aspect of the figure is that while some students thought they improved on a teamwork skill, their fellow team mates actually thought that they got worse. These opposite-opinion assessments can be identified as a positive change in "self" coupled with a negative change by "others" as listed below:

#3 Respects individual viewpoints or differences,
#6 Listens attentatively to others on team,
#9 Makes decisions based on facts,
#12 Monitors self-progress,
#13 Completes individual tasks thoroughly and,
#15 Asks for help when needed.

For example, the data appear to indicate the while each student thought she improved her skill to "ask for help when needed," however her teammates actually felt the contrary.

At mid-semester (MS) and the end-of-the-semester (ES), students were permitted to comment on any aspect of teamwork in the "Comments A" box. A sample of these is shown in Table 8 below as either MS-A or ES-A. Then after each student reviewed his own averages, he was asked to suggest ways in which he could improve them. These were entered in the "Comments B" box. Most of the comments were positive and thoughtfully introspective. Most were optimistic about how well their team was operating.

Table 8. Sample of student comments from the mid-semester (MS) and end-of-semester (ES) teamwork evaluation reports.

Student	Period	Comment
A	MS-A	Team is very good. No problems.
	MS-B	It seems as though my average is lower than the group average. It looks like some group members agree that I have a problem accepting criticism. I probably need to try to be more open and accepting to other people's views, even if I don't agree with what they are saying.
	ES-A	As the project manager for this portion of the design project, I was very pleased with my group's work on the preliminary design report.
	ES-B	I thought that I handled criticism better this time than last evaluations, I took on a heavier load this time, that is why one team member thought I didn"t ask for help when I needed it, because I was content doing it myself.
B	MS-A	There are no teamwork issues on this team that I am aware of
	MS-B	They (ratings) are pretty close, again I do not believe there are any teamwork issues on this team
	ES-A	This is a good team, our individual strengths compliment the team well.
	ES-B	I don't see any issues with the way the ratings compare
C	MS-A	Right now, we are working together very well.
	MS-B	Rather than look at the slight difference in the averages, I see the scores as nearly the same. This proves to me that we are all on the same page.
	ES-A	We are still working well as a team and are excited about building and testing next semester.
	ES-B	I think my self average is pretty close to what the others rated me. I will try to listen to and respect other viewpoints better and also keep more in touch with the other team members about my progress on personal tasks.
D	MS-A	The group works well together, but sometimes we get lazy. This pretty much applies to the whole group. There are no individuals that are specifically trouble in any area.
	MS-B	My teammates averaged a rating for me that was just a little bit higher than what I rated myself. It appears that I participate more actively and communicate clearer than what I feel I do. So apparently I am doing a good job,
	ES-A	As a team, we work very well together. I feel our group dynamics are great. As long as we remain focused, complete all of our tasks on time and keep moving forward, we should continue to progress successfully.
	ES-B	Our group work was a little more individually driven towards the end of the semester. Also I could have been tougher on myself. I don't want to get comfortable with any laziness.

In years past, when this teamwork evaluation system was not used, more teams experienced issues such as major misunderstandings and out-right hostility towards each other. Further data from the spring semester will be collected, analyzed and reported at next year's conference.

Summary

Winning sports teamwork can be analyzed to compare essential aspects of professional sports' teamwork such as communication, individual skills, team skills and risk management to effective engineering design project teamwork.

Four broad elements of teamwork can be described as collaboration, communication, team decision-making, and self-management. These can be further broken down into 15 skills which can be assessed using an ordinal rating system.

A senior design project course, which emphasizes teamwork, was described along with its framework of pre-requisite courses.

The development and use of a teamwork evaluation spreadsheet tool was discussed including the 15 measured teamwork skills, self-reflection activities and peer evaluation analysis. Seniors use the tool, as feedback on their teamwork performance, four times during their year long design project.

Preliminary results from the first semester, of the two course sequence, indicate that many of the students are improving in many of their teamwork skills. While there is substantial agreement between how the students evaluate themselves, sometimes the student's team members disagree as to the amount of improvement.

References

[1.] Lewis, J. P., *Fundamentals of Project Management*, American Management Association, New York, N.Y., 2002.

[2.] Badiru, A. B., P. S. Pulat, Comprehensive *Project Management*. Prentice Hall, Englewood Cliffs, N.J. 1995

[3.] Katzenbach, J. R. and Smith, D. K., *The Wisdom of the Team*, Harvard Business School Press, Boston, M.A., 1993

[4.] Dutson, A., Todd, R., Magleby, S., and Sorenson, C., "A Review of the Literature on Teaching Engineering Design Through Project-Oriented Capstone Courses," *Journal of Engineering Education*, January 1997, pp. 17-28.

[5.] Davis, D., Gentili, K., Trevisan, M., and Calkins, D., "Engineering Design Assessment Processes and Scoring Scales for Program Improvement and Accountability," *Journal of Engineering Education*, April 2002, pp. 211-221.

[6.] Howe, S. and Wilbarger, J., "2005 National Survey of Engineering Capstone Design Courses", *Proceedings of the 2006 ASEE Annual Conference and Exposition*, ASEE, 2006.

[7.] Todd, R., Magleby, S., Sorenson, C., Swan, B., and Anthony, D., "A Survey Of Capstone Engineering Courses In North America, *Journal of Engineering Education*, April 1995, pp. 165-174.

[8.] Eggert, R., "Engineering Design Education: Surveys of Demand and Supply," *Proceedings of the 2003 ASEE Annual Conference & Exposition*, June 2003, Nashville, TN.

[9.] Eggert, R., "Design for Manufacture and Assembly: A Survey of Desired Competencies," *Proceedings of the 2006 ASEE Annual Conference & Exposition*, June 2006, Chicago, IL.

[10.] McGourty, J. and DeMeuse, K. P., *The Team Developer: An Assessment and Skill Building Program*, John Wiley & Sons, Inc., New York, N.Y. 2001.

[11.] Eggert, R., *Engineering Design*, Prentice Hall, Inc., 2004, Englewood Cliffs, New Jersey

[12.] Tuckman, B., "Developmental Sequence in Small Groups," *Psychological Bulletin*, no.63, 1965.