Strategies for Developing Engineering Student's Teamwork and Project Management Skills

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Abstract

Engineering students are increasingly expected to work in teams and participate in projects. These expectations are motivated by employer expectations, ABET EC2000 criteria, and research on the importance of active and cooperative learning. Seldom is there explicit attention paid to helping students develop teamwork and project management skills. This paper outlines essential teamwork and project management skills and provides materials and suggestions for helping students develop these skills.

Teamwork

Teamwork is common in engineering. Technical competence is necessary of course, but it's not sufficient. The importance of teamwork is routinely stressed by business leaders. For example, the current CEO of General Electric, John F. Welch, recently said (December, 1993): "If you can't operate as a team player, no matter how valuable you've been, you really don't belong at GE.". Effective teamwork is not easy to accomplish. Engineering professor Douglas J. Wilde said "It's the soft stuff that's hard, the hard stuff is easy." Larry Leifer, Director of the Stanford Center for Design Research, reports "Design team failure is usually due to failed team dynamics."

Strategy One

Acknowledge that not all teamwork is successful by showing group performance curve (Figure 1). This typically resonates with some of their experiences. Ask students to reflect on successful and effective team experiences, share them with one another in small groups, and to list common characteristics. Develop a joint list of characteristics of effective groups. Comment on the different types of groups and their characteristics, and compare students' list with Katzenbach and Smith's (1993):

> ***A team is a small number of people with complementary skills who are committed to a common purpose, performance goals, and approach for which they hold themselves mutually accountable.***

Types of Teams

There is nothing magical about teamwork in engineering. For example, some types of teams increase the quality of life and facilitate accomplishments. Other types of teams hinder productive work and create disharmony and dissatisfaction. To use teamwork effectively, you must know what is and what is not an effective group.

There are many types of teams that can be used in engineering. Cooperative groups are just one of them. When you choose to use (or are asked or required to use) groups, you must ask yourself *"What type of group am I involved in"?* The following checklist may be helpful in answering that question (See Figure 1).

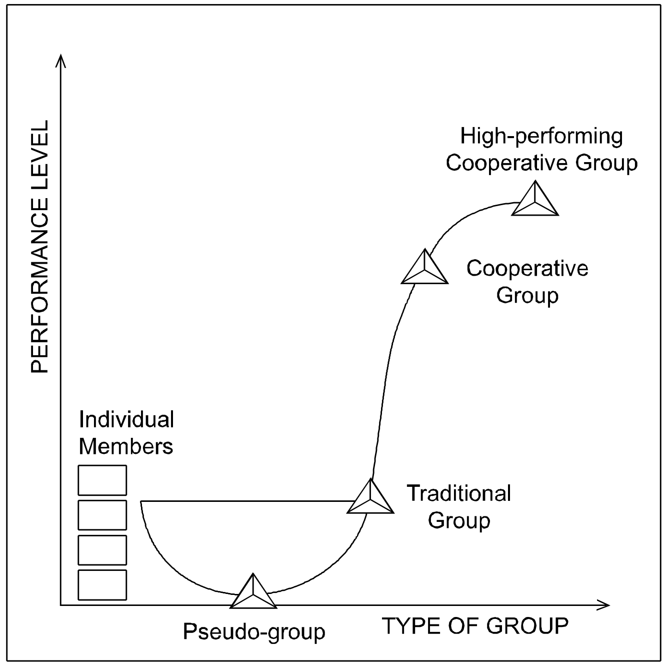

Figure 1 Group Performance

1. **Pseudo Group**: Members are assigned to work together but they have no interest in doing so. They believe they will be evaluated by being ranked from the highest performer to the lowest performer. While on the surface members talk to each other, under the surface they are competing. They see each other as rivals who must be defeated, block or interfere with each other's learning, hide information from each other, attempt to mislead and confuse each other, and distrust each other. Members would achieve more if they were working alone.

2. **Traditional Group:** Members are assigned to work together and accept that they must do so. Assignments are structured, however, so that very little joint work is required. Members believe that they will be evaluated and rewarded as individuals, not as members of the group. They interact primarily to clarify how assignments are to be done. They seek each other's information, but have no motivation to teach what they know to their groupmates. Helping and sharing is minimized. Some members loaf, seeking a free ride on the efforts of their more conscientious groupmates. The conscientious members feel exploited and do less. The result is that the sum of the whole is more than the potential of some of the members, but the more hard working and conscientious members would perform higher if they worked alone.

3. **Cooperative Groups:** Members are assigned to work together and, given the complexity of the task and the necessity for diverse perspectives, they are relieved to do so. They know that their success depends on the efforts of all group members. The group format is clearly defined. **First**, the group goal of maximizing all members' learning provides a compelling common purpose that motivates members to roll up their sleeves and accomplish something beyond their individual achievements. **Second**, group members hold themselves and each other accountable for doing high quality work to achieve their mutual goals. **Third**, group members work face-to-face to produce joint work-products. They do real work together. Members promote each other's success through helping, sharing, assisting, explaining, and encouraging. They provide

both academic and personal support based on a commitment to and caring about each other. **Fourth**, group members are taught teamwork skills and are expected to use them to coordinate their efforts and achieve their goals. Both task and teambuilding skills are emphasized. All members share responsibility for providing leadership. **Finally**, groups analyze how effectively they are achieving their goals and how well members are working together. There is an emphasis on continual improvement of the quality of learning and teamwork processes.

4. **High-Performance Cooperative Group:** This is a group that meets all the criteria for being a cooperative learning group and outperforms all reasonable expectations, given its membership. What differentiates the high-performance group from the cooperative group is the level of commitment members have to each other and the group's success. Jennifer Futernick, who is part of a high-performing, rapid response team at McKinsey & Company, called the emotional binding of her teammates together a form of love (Katzenbach & Smith, 1993). Ken Hoepner of the Burlington Northern Intermodal Transport Team (also described in Katzenbach & Smith, 1993) stated: "Not only did we trust each other, not only did we respect each other, but we gave a damn about the rest of the people on this team. If we saw somebody vulnerable, we were there to help." Members' mutual concern for each other's personal growth enables high-performance cooperative groups to perform far above expectations, and also to have lots of fun. The bad news about extraordinarily high-performance cooperative learning groups is that they are rare. Most groups never achieve this level of development.

Katzenbach and Smith summarize the major differences between working groups and teams in the following table:

Not All Groups Are Teams: How to Tell the Difference
(Katzenback & Smith, 1993)

Working Group	Team
Strong, clearly focused leader	Shared leadership roles
Individual accountability	Individual and mutual accountability
The group's purpose is the same as the broader organizational mission	Specific team purpose that the team itself delivers
Individual work-products	Collective work-products
Runs efficient meetings	Encourages open-ended discussion and active problem-solving meetings
Measures its effectiveness indirectly by its influence on others	Measures performance directly by assessing collective work-products
Discusses, decides, and delegates	Discusses, decides, and does real work together

A common way to promote more constructive and productive teamwork is to have the teams create a set of guidelines for the group, sometimes called group norms or a team charter.

Common features of team charters include:

- Team name, membership, and roles
- Team Mission Statement
- Anticipated results (goals)
- Specific tactical objectives
- Ground rules/Guiding principles for team participation
- Shared expectations/aspirations

Strategy Two

Periodically ask each group to reflect on how well they're working together. My favorite processing strategy is the Boeing Plus/Delta, where students are asked to list things that are going well and things they can improve. Randomly invite students to share things that are going well. Ask groups to problem solve things that need to be improved. Processing can help you and the students identify skills and competencies that are needed for effective group work. Some of the essential technical and human skills for effective project management are summarized below.

Project Management

[A project is] a combination of human and nonhuman resources pulled together in a temporary organization to achieve a specified purpose (Cleland & Kerzner, 1985). The following list summarizes the principal features of projects (Nicholas, 1990).

- Definable purpose with established goals
- **Cost, time** and **performance** requirements
- Multiple resources across organizational lines
- One-time activity
- Element of risk
- Temporary activity
- Process of phases/project life cycle•

Project management is increasingly seen as a combination of human and technical skills needed to help a group of people work together to accomplish a task (Lewis, 1998; Smith, 2000). Barry Posner (1987) conducted a survey of project managers, asking them "what it takes to be a good project manager." He got the following results:

1. Communications (84% of the respondents listed it)
   - Listening
   - Persuading
2. Organizational skills (75%)
   - Planning
   - Goal-setting
   - Analyzing

3. Team Building Skills (72%)
   - Empathy
   - Motivation
   - Esprit de Corps
4. Leadership Skills (68%)
   - Sets Example
   - Energetic
   - Vision (big picture)
   - Delegates
   - Positive
5. Coping Skills (59%)
   - Flexibility
   - Creativity
   - Patience
   - Persistence
6. Technological Skills (46%)
   - Experience
   - Project Knowledge

Human Aspects – Leadership

Kouzes and Posner (1987, 1993) found that when leaders do their best, they challenge, inspire, enable, model, and encourage. They suggest ten commitments of leadership:

Challenging the Process

1. Search for Opportunities
2. Experiment and Take Risks

Inspiring a Shared Vision

3. Envision the Future
4. Enlist Others

Enabling Others to Act

5. Foster Collaboration
6. Strengthen Others

Modeling the Way

7. Set the Example
8. Plan Small Wins

Encouraging the Heart

9. Recognize Individual Contribution
10. Celebrate Accomplishments

Leadership actions that are essential to effective teams include communication and appropriate norms of trust and loyalty, and effective decision making and constructive conflict management

Human Aspects – Decision Making

Several methods have been described in the literature for making decisions. One of my favorites is from Johnson & Johnson (1991). They list seven methods for making decisions:

1. Decision by authority without discussion.
2. Expert member.
3. Average of members' opinions.
4. Decision by authority after discussion.
5. Majority control.
6. Minority control.
7. Consensus.

The most important feature of group decision making is that the group has a variety of strategies for making decisions and deliberately chooses the most appropriate approach.

Human Aspects – Conflict Management

Conflict is a routine aspect of every project managers job. **Conflict** is defined as "a situation where an action of one person prevents, obstructs, or interferes with the actions of another person." On complex projects and tasks, highly talented and motivated people routinely disagree about the best ways to accomplish tasks and especially how to deal with trade-offs among priorities. So conflict arises! A conflict situation often is a "moment of truth" since it can follow either a constructive or a destructive path.

A common model for analyzing approaches to conflict is Blake and Mouton. They used two principles axes to represents the conflict strategies – (1) The importance of the goal and (2) and importance of the relationship. The five strategies are described as follows:

<u>*Conflict Strategies*</u>

Withdrawal - Neither the goal nor the relationship are important - you withdraw from the interaction.

Forcing - The task is important but not the relationship - use all your energy to get the task done.

Smoothing - The relationship is more important than the task. You want to be liked and accepted.

Compromise - Both task and relationship are important but there is a lack of time - you <u>both</u> gain and lose something.

Confrontation - Task and relationship are equally important. You define the conflict as a problem-solving situation and resolve through negotiation.

Each of these strategies is appropriate under certain conditions. For example, if neither the goal nor the relationship is important to you, then often the best thing to do is withdraw! If the relationship is extremely important and the task is not so important (at the time), then smoothing is appropriate.

In many conflict situations, both the task and the relationship are important. In these situations, confronting and negotiating often leads to the best outcomes.

Technical Aspects – Project Planning

Projects typically start with at Statement of Work (SOW) provided by the client. The statement of work is a narrative description of the work required for the project. Planning starts with the development of a Work Breakdown Structure (WBS). A WBS is "a deliverable-oriented grouping of project elements which organizes and defines the total scope of a project" (Duncan, 1996).

A possible work breakdown structure (WBS) for an office remodeling project could include

Procurement
- Order Paint
- Procure New Carpet
- Procure New Furniture

Preparation
- Remove Old Furniture
- Remove Old Carpet
- Scrub Walls

Installation
- Paint Walls
- Install New Carpet
- Install New Furniture

A list is a common format for a WBS, as are organizational diagrams, and Post-It notes networks.

Technical Aspects – Scheduling

Project management involves the task of scheduling a series of jobs with the ultimate aim of getting the entire project completed at the lowest total cost possible. This is most often achieved by minimizing the time required to finish the project and then by utilizing the resources required in the most efficient manner.

Provided that the number of activities is not too large, problems of this type can often be solved by hand. For example, consider the accompanying 'bus shelter' problem. By sketching the relationships between the individual tasks, and taking into account the amount of time each requires for completion, we can determine the total amount of time needed to get the whole process completed.

Critical Path Method. A simple and systematic way of doing this is provided by the **Critical Path Method**. This method represents the flow of tasks in the form of a network. To use it we simply have to know the duration of each of the activities, and the predecessors of each, i.e. the set of activities that must have terminated before an activity can begin. The following example illustrates the critical path method.

Table 1. Bus Shelter Construction Example

Job	Name	Duration	Resources	Predecessor(s)
1	Shelter Slab	2	2	5
2	Shelter Walls	1	1	1
3	Shelter Roof	2	2	2,4
4	Roof Beam	3	2	2
5	Excavation	2	3	
6	Curb and Gutter	2	3	5
7	Shelter Seat	1	2	4,6
8	Paint	1	1	7
9	Signwork	1	2	2,6

The method then represents the problem in the form of a precedence network, as shown in Figure 2.

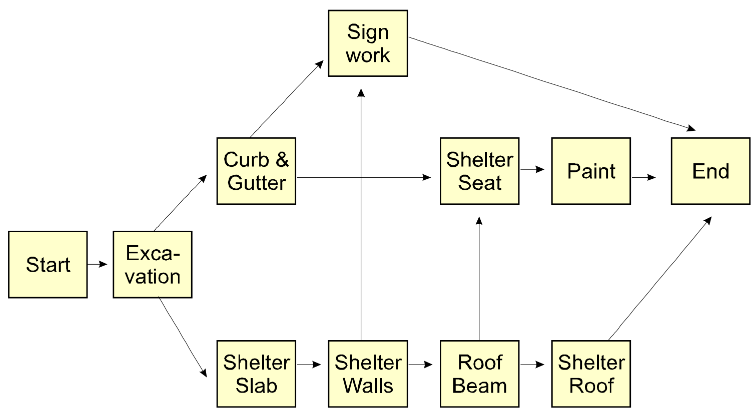

Figure 2 WBS/Precedence Network for Bus Shelter

Critical Path. Activities for which the earliest and latest starting times turn out to be equal are call **critical**, i.e. they cannot be delayed without delaying the duration of the entire project. The path that these activities lie on in the network is known as the **critical path**. The remaining **non-critical** activities have some slack and can have their durations increased by some amount before they would become critical and delay the total duration. The numerical solution to the problem is given in Table 2.

The last figure (Figure 3) is a time-scaled network (GANTT chart) where the activities have been laid out on a time axis.

The Role of Computer-Based Project Management Software. It is not hard to see that if we were to add a few more activities, the problem would soon become unmanageable by hand. Further, if changes have to be made either to the order in which activities must occur, or in the time in which they can be completed, the entire process would have to be repeated. The advantage of the critical path method is that it is indeed systematic and can be described as a formal set of instructions which can therefore be followed by a computer. Then alterations in the data could be made repeatedly and the problem quickly solved again by the machine. This would enable us to obtain the benefit of 'what if' analysis, the process of making changes and getting effects of

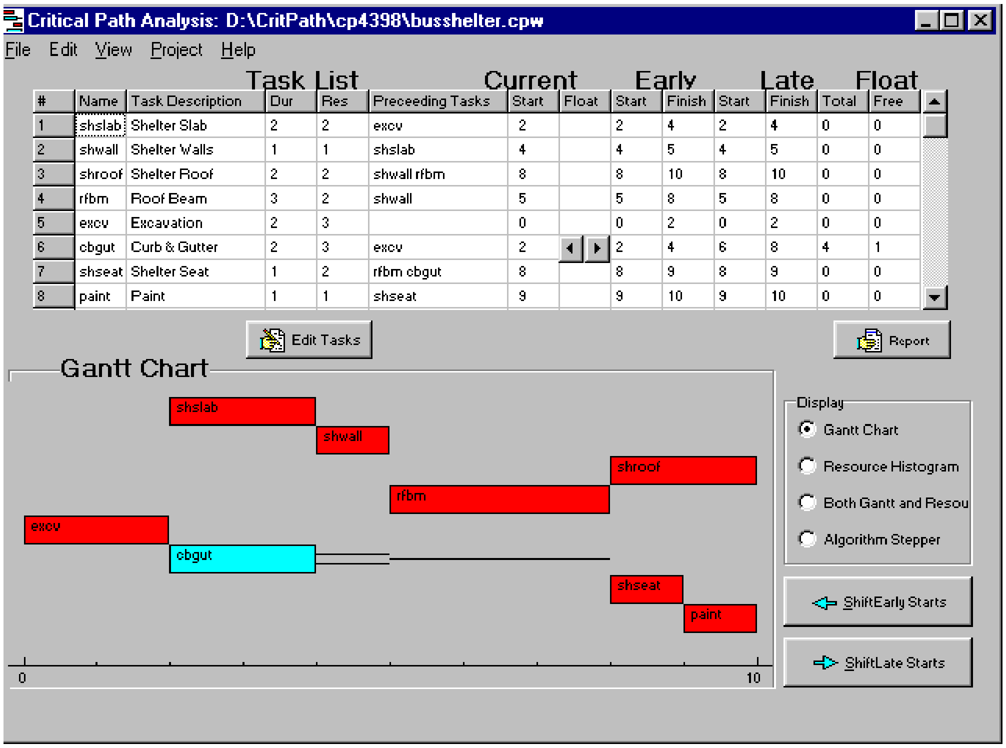

Figure 3 Gantt Chart for Bus Shelter

those changes immediately. Such analysis gives the user an intuitive feel for the problem. There are numerous project scheduling software programs (Microsoft Project, Primavera, etc.). If you would like to try out a simple, easy-to-use program, **CritPath** is available for downloading from www.ce.umn.edu/~smith.

Table 2. Bus Shelter Construction – Critical Path Method Results

ACT	NAME	DUR	RES	EARLY		LATE		FLOAT		CUR start	CRIT PATH
				ST	FN	ST	FN	TOT	FREE		
1	Shelter Slab	2	2	2	4	2	4	0	0	2	YES
2	Shelter Walls	1	1	4	5	4	5	0	0	4	YES
3	Shelter Roof	2	2	8	10	8	10	0	0	8	YES
4	Roof Beam	3	2	5	8	5	8	0	0	5	YES
5	Excavation	2	3	0	2	0	2	0	0	0	YES
6	Curb and Gutter	2	3	2	4	6	8	4	1	2	NO
7	Shelter Seat	1	2	8	9	8	9	0	0	8	YES
8	Paint	1	1	9	10	9	10	0	0	9	YES
9	Signwork	1	2	5	6	9	10	4	4	5	NO

Strategy Three

Periodically ask individual students to list problems they are having either in working with their group or in accomplishing the task, to share the problems in their group and to make a common list. Randomly collect a list of problems from the class, ask each group to choose one problem, and (1) brainstorm possible solutions and (2) develop a plan for solving, resolving, or eliminating the problem. Quickly survey the class to find out what problem they chose.

Many of the problems that formal teams face during significant projects, such as capstone design projects, can be minimized or eliminated by providing students with extensive informal and formal cooperative learning experiences throughout their undergraduate education.

Cooperative Learning

An effective way to implement teamwork in engineering is through the cooperative learning approach. **Cooperation** is working together to accomplish shared goals. Within cooperative activities individuals seek outcomes that are beneficial to themselves and beneficial to all other group members. **Cooperative learning** is instruction that involves people working in teams to accomplish a common goal, under conditions that involve both *positive interdependence* (all members must cooperate to complete the task) and *individual <u>and</u> group accountability* (each member is accountable for the complete final outcome). A large and rapidly growing body of research supports the effectiveness of cooperative learning in higher education. Relative to team members taught traditionally (i.e. primarily with lectures and individual homework assignments), cooperatively taught team members tend to have longer information retention, better performance on exams, higher grades, stronger critical thinking and problem-solving skills, more positive attitudes toward the subject and greater motivation to learn it, better interpersonal and communication skills, higher self-esteem, and if groups are truly heterogeneous, improved race and gender relations. The key features of effective cooperative learning groups are (Johnson, Johnson & Smith, 1991, 1998):

Positive Interdependence exists when team members believe that they are linked with others in a way that one cannot succeed unless the other members of the group succeed (and vice versa). Team members are working together to get the job done. In a problem-solving session, positive interdependence is structured by group members (1) agreeing on the answer and solution strategies for each problem (common goal interdependence) and (2) fulfilling assigned role responsibilities (role interdependence).

Face-to-Face Promotive Interaction exists among team members when they orally explain to each other how to solve problems, discuss with each other the nature of the concepts and strategies being learned, teach their knowledge to classmates, and explain to each other the connections between present and past learning.

Individual Accountability/Personal Responsibility requires the professor to ensure that the performance of each individual student is assessed and the results given back to the group and the individual. The group needs to knows who needs more assistance in completing the assignment and group members need to know they cannot "hitch-hike" on the work of others.

Teamwork Skills are necessary for effective group functioning. Team members must have and use the needed leadership, decision-making, trust-building, communication, and conflict-management skills. Effective groups not only accomplish the task, they also improve the members' teamwork skills.

Group Processing involves a group discussion of how well they are achieving their goals and how well they are maintaining effective working relationships among members. At the end of their working period the groups process their functioning. A common processing approach (used by Boeing, for example) is **plus/delta**. Plus/delta processing is accomplished by listing all the things the group did well and all the things they could improve.

Cooperative learning research has documented the effectiveness of the approach for student learning, especially for the most technically complex and conceptually dense materials (Johnson, Johnson, and Smith, 1991, 1998a, 1998b). With a little time and attention, faculty can also use cooperative learning strategies to help students develop project management and teamwork skills.

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