Valuable Lessons from the Successes and Failures of Teams of Engineering Students

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ABSTRACT
Performance of engineering students at regional, national and international competitions is often used as benchmarks for assessment of the quality of the education provided by their undergraduate institution. In such competitions, the potential for success of a small program entering the competition for the first or second time may be significantly different than that of a larger institution which has entered the competition several times previously. The authors, as advisors of two different ongoing projects share their years of experience with those colleagues who are interested in sponsoring engineering students in such challenging competitions. They briefly discuss elements of group dynamics and discuss why the success rate of the projects depends heavily on successful team building. They discuss steps for successful creation of teams that the strength of their members complement each other and propose tested techniques that may significantly enhance the relative potential of such teams. The instrumental role of the advisor is discussed. His/her project management activities must gradually be taken over by one or several members of the team. S/he must clearly establish the goals of the project and the expected performance criteria. The level of such expectations/goals may be significantly different than those set for winning the competition. The teams that achieve these initially set goals of their own environment are considered successful. The most important outcome of such projects is the experience that the students gain by their involvement in a cooperative learning environment through which they enhance their overall knowledge of engineering and improve their group dynamics skills.

I- INTRODUCTION
For the past twenty two years, The College of New Jersey-TCNJ (formerly known as Trenton State College) has developed and prepared many vehicles for competitive events. In 1983 we built our first Mini-Baja vehicle as part of our Senior Design Project activity and since then, new groups of students have been designing and building completely new and distinct vehicles for SAE's "Mini Baja East". In 1992 we started a second group building a solar/electric car to participate in NESEA's "American Tour deSol". These two groups were working side-by-side when in 1995 we added a third group whose task was to design a Lunar Rover to compete in NASA's "Great American Moonbuggy Race". When the advisor for the solar/electric car retired, the faculty felt that the department needed to maintain several opportunities for students to become involved in "group senior design activities." The department's history of success in

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national competitive events encouraged us to initiate yet another project. A group of students was to design and fabricate a solar/electric boat with which to compete in ASME's 1999 "Solar Splash". These groups operate within our relatively small program, without funding from the department.

We approach each competitive event with several goals in mind. First is to win the event with the best engineered, most finely prepared vehicle possible. The second goal is to finish every event that we enter. The third goal is to bring the vehicle, and driver(s), back in one piece. The common denominator, the basis for any success that we may enjoy, and the reason why all these activities were organized in the first place, is the involvement of students in a cooperative learning environment – a team effort [1]. Edgar Dale relates an "ancient proverb" that states, "Tell me, and I forget; Show me and I remember; Involve me and I understand" [2]. It is this involvement that has led us to formalize the active group learning experience, and equate this team structure with the recognized *"Cooperative Learning Experience"* [3].

II – STRUCTURE

At The College of New Jersey, starting from their first semester, and throughout their sophomore, junior and senior years, students are involved with projects that involve them with group activities. They are assigned to teams of two, three, four or more students depending on the nature of the project/activity at hand.

The first discussions of group dynamics, of team development, and the interdependence of team members are held in the first engineering course in the first semester. These concepts are further developed and repeatedly exercised and further polished in future classes [1]. As shown in table (1), students are involved in team work activities in twelve different courses *prior* to their senior year.

Finally, in their two-semester "senior design project" (the capstone engineering design course), students review, reinforce, and synergize all the previously learned concepts of their education (including team work concepts). They use the full two semesters to work on one design project of their choosing. One member of the group is usually from the engineering management concentration and serves as the team manager. This provides structure, organization, and time management of the group's efforts. In addition to the primary advisor, there may be collaborating advisor(s) providing any necessary technical support.

III– ESSENTIAL ELEMENTS OF TEAM DEVELOPMENT

According to Carl Smith, "Base groups are long-term, heterogeneous cooperative learning groups with stable membership whose primary responsibility is to provide each student the support, encouragement, and assistance he or she needs to make academic progress" [4]. This is the transformation process that changes a group of individuals into a fully functioning, cohesive group.

Table (1) reflects on the evolutionary process of preparing the students for their demanding tasks in their senior year. *The remainder of this section briefly discusses the steps taken in forming and developing Senior Project Teams with the specific intention to participate in a national or international collegiate competitive event.*

Course Title	Year Taken	Term Taken	Nature of the Design Activity/Project				TEAM WORK
			Laboratory Experiment.	Reverse Engineer.	Mini-Design Project(s)	Final Design Project	
Fund. Eng. Design	**1**	**1**		Y		Y	Y
Creative Design	**1**	**2**				Y	Y
Manufacture. Process	**2**	**1**		Y			Y
Engineering Materials	//	//	Y				Y
Mech. of Materials	**2**	**2**			Y	Y	Y
Mech. Lab I	//	//	Y		Y		Y
Society, Ethics & Tech.	**3**	**1**				Y	Y
Mech. Design Anal. I	//	//			Y	Y	Y
Thermodynamics. II	**3**	**2**				Y	Y
Fluid Mechanics	//	//				Y	Y
Kinematics & Mech.	//	//		Y	Y	Y	Y
Mech. Lab. II	//	//	Y				Y
Heat Transfer	**4**	**1**				Y	Y
Control Systems	//	//			Y		Y
Control Sys. Lab.	//	//	Y				Y
Mech. Lab III	//	//	Y		Y		Y
Senior Project I	//	//				Y	Y
Mech. Lab IV	**4**	**2**	Y		Y		Y
Mech. Elective	//	//			Y		Y
Senior Project II	//	//				Y	Y

Table 1 Associated Team Work in the Mechanical Engineering Program at TCNJ.

First of all, in our team building structure, members are selected from a group of interested applicants. Many of these applicants have volunteered, as underclassmen, to help earlier senior design teams prepare for an event. They know what is involved in participating in such an activity. They have witnessed that the success of the team depends upon the efforts of all the team members. Johnson, Johnson, & Smith [3] call this element *"Positive Interdependence"*.

Secondly, all of our teams have at least one formal meeting scheduled each week. These meetings are structured so that each of the members not only presents the status of their part of the project, but also explains the nature of the concepts and strategies utilized in the process. Again Johnson, Johnson, and Smith characterize this element of team development as *"Face-To-Face Promotive Interaction"*.

One of the outcomes of these weekly meetings is that the group begins to develop an awareness of those members who need help. The group needs to know who needs assistance in accomplishing their part of the project. It is the opportunity for the group to assess the accomplishments of its members, and to assure that each member is held accountable for their part of the project. Johnson, Johnson & Smith call *this "Individual Accountability/Personal Responsibility."*

Each group should have one member with "Engineering Management" background. His/Her role in leadership, decision making, trust building, communication, and conflict management is invaluable. This member should preside over the meetings, and create critical path network scheduling. This should insure that all elements of the project come together in an organized and timely manner.

IV – STAGES OF TEAM DEVELOPMENT

As the group of individuals come together to begin forming a group, they will pass through several predictable phases as they progress from separate individuals to a cohesive group. In 1965, Bruce Tuckman [5] published his "Forming, Storming, Norming, and Performing" team development model. This elegant model has served as the basis for a host of similar models that have been developed in the almost three decades since its original publication. The Forming, Storming, Norming, and Performing stages of team development form a basis for understanding the team developmental process. A team must be able to identify which stage they are in, and manage the transition form one stage to another adeptly [1].

To enforce accountability, we decided to create *"The Group Activities Evaluation Form."* This form is offered in Appendix (1) for potential adaptation or modification. The students are required to responsibly fill and include this form as an integral part of each of their team-oriented activities. Such activities may be laboratory experiments or design projects starting from the freshman year and continuing through the senior year (as listed in Table (1)). In general, statistical analyses of the data from these evaluation forms (conducted by all colleagues at this program) reveal that there is a direct correlation between the success rate of the groups and their abilities to function as a team.

V – THE ROLE OF THE ADVISOR

George Ettenheim suggests that "If a faculty advisor holds the reins too tightly, the students may lose interest. If the students are without an advisor, the lack of experience may hurt" [6].
In either case, there are several common tasks that each advisor must perform. They start with the analysis of the rules and regulations of the competitive event and determination of the number and type of engineering design activities that warrant academic credit at the senior design project level. This then dictates the number, and background, of students required to carry off the project. In our case, team sizes average from four (4) to six (6) members. In almost every project, there always seems to be a myriad of little design problems that do not fit into the above classification. These are excellent problems that can be assigned to underclassmen volunteers. They are always eager and willing helpers. This is a highly promising group that the advisor may select future team members.

The advisor will select the team members from a group of applicants as opposed to the students choosing their partners. S/He should be familiar with the academic performance, problem solving skills, motivation level, and of course, the work ethics of all potential members. The task then becomes matching the requirements of the project with the potential candidates.

The first organizational meetings, of a new team, are critical to group development. The advisor must clearly define the elements of the project, as well as the interrelationship of the various elements. Each member of the team must be critically aware of their personal responsibility, how their part relates to the other members' parts, and how all of the elements are dependent on one another – *positive interdependence and individual accountability*. It is necessary that the advisor meet individually with each member of the team to develop a personal contract with the student. This contract lists specifically each element that the student is going to accomplish, to what extent, and under what conditions. This then becomes the basis for grading the student's progress at the end of the semester. In Appendix (2), we have included *"The Senior Project Proposal form"* along with the Grade Weighting Criteria (used at TCNJ engineering programs) for potential adaptation or modification.

VI - SUMMARY OF THE STRATEGY

Tables (2) and (3) provide a tested summary of the steps and strategies that may prove helpful in the successful development of teams. Table (4) displays the performance record of the students in the mechanical engineering program at The College of New Jersey in regional, national and international student design competitions. The effectiveness of what we have proposed in this paper may be measured through the results shown in this table.

VII – CONCLUSIONS

This paper proposes that Team Work projects be established as part of each level of academic preparation. These activities should be based upon a well-founded cooperative learning environment, and that the team work experiences reflect this foundation. The essential elements of team development should be firmly established as early in the engineering education as possible and continuously exercised and reinforced throughout the remaining years. Early analysis of the graduates of this program seems to indicate that they are measurably better prepared for engineering leadership and management positions.

PLANNING THE PROJECT	
1.	Evaluate the feasibility of conducting the project with regard to its required finances, human resources, equipment, facilities, deadline for completion, etc.
2.	Recruit members that their interpersonal and intellectual skills complement each other.
3.	Set realistic expectations and challenge each of the members at a level that they may succeed.
4.	Prepare a preliminary timetable for major activities involved in the project.
5.	Establish a clear grading policy that is consistent with project's objectives and its requirements.

Table 2 Suggestions for Planning the Project.

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	CONDUCTING THE PROJECT
1.	Plan a comprehensive first meeting, reviewing all objectives, rules and regulations and logistical issues related to the project.
2.	Review the role of each member as an individual contributor and make it clear that the success of the team depends on the performance and dedication level of each of the members.
3.	Provide sources of information for conducting research and obtaining related literature.
4.	Inform the new team about the existing network of support for obtaining financial and professional assistance.
5.	Discuss the synergistic nature of the design and team work activity and provide examples of success and failure using prior experiences, etc.
6.	Set up a regular weekly time for group meetings that is compatible with every member's schedule and emphasize on the importance of participation of all members.
7.	Make them aware that a later change of design in one of the components/subsystems of the product may create a "Domino Effect" on many other components/subsystems.
8.	Have the entire team work with the project manager to generate a Gantt chart and a Critical Path Network.
9.	Have all members provide a progress report on weekly-basis and discuss/brainstorm the potential solutions for the newly encountered/unforeseen problems.
10.	Encourage members to finalize a (seemingly) flawless and promising design before they start fabrication.
11.	Encourage/require the team to test the functionality/practicality of their proposed designs by computer simulations and actual prototyping.
12.	Establish ample hours for the project, and make yourself available for all team members.
13.	Have the entire team make a presentation to previous year team members and all involved supporting individuals/collaborating advisors at critical stages of the project.
14.	Encourage the previous year team members to provide support and advice for the young/inexperienced team.
15.	Establish a rewarding and appreciation system for all the parties involved.

Table 3 Suggestions for Improving the Chances of Success for a Team Based Project.

Year	Competition Title	Competition Level			# of Schools	TCNJ Placement
		Regional	National	International		
1998	Mini-Baja, Eastern Region	Y			40+	Top Ten Overall
1998	5th. Annual Great Moon-Buggy Race		Y		30+	1st Place; National Championship
1999	Mini-Baja, Eastern Region	Y			40+	Top Ten Overall
1999	Solar Splash Solar/Electric Boat Regatta			Y	20+	Rookie Team with Best Overall Score, 2nd Place; Technical Report
1999	6th. Annual Great Moon-Buggy Race		Y		30+	AIAA's Best Engineering Design Award
2000	Mini-Baja, Eastern Region	Y			40+	Top Ten Overall
2000	Solar Splash Solar/Electric Boat Regatta			Y	20+	1st Place; Technical Report and Best Visual Displays
2000	7th. Annual Great Moon-Buggy Race		Y		30+	1st Place; National Championship
2001	Mini-Baja, Eastern Region	Y			40+	4th place in Endurance 6th overall
2001	Solar Splash Solar/Electric Boat Regatta			Y	20+	1st Place; Technical Report and Best Visual Displays
2001	8th. Annual Great Moon-Buggy Race		Y		30+	3rd Place National Championship
2002	Mini-Baja, Eastern Region	Y			40+	Best Engineering Design, Honda Best Performance Award 2nd. Place Overall
2002	Solar Splash Solar/Electric Boat Regatta			Y	20+	Best Technical Report, 2nd Place; Visual Displays, Outstanding Electrical Design, & Outstanding Workmanship
2002	9th. Annual Great Moon-Buggy Race		Y		30+	AIAA's 2002 Best Engineering Design Award
2003	Mini-Baja, Eastern Region	Y			40+	1st place, Endurance, Honda Best Performance Award 4th. Place Overall
2003	Solar Splash Solar/Electric Boat Regatta			Y	20+	Best Technical Report, 2nd Place; Visual Displays, Outstanding Electrical Design, & Outstanding Workmanship
2004	Mini-Baja, Eastern Region	Y			40+	Best Engineering Design, 2nd. Place Overall
2004	Solar Splash Solar/Electric Boat Regatta			Y	20+	Best Technical Report, 1st. Place; Visual Displays, Outstanding Electrical Design

Table 4 Performance Record of TCNJ in National and International Competitions

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APPENDIX: 1

Group Activities Evaluation Form

Group activities provide settings where students can be both intellectually active and personally interactive. Evaluate your group's performance on each of the five essential elements of a well-structured learning group.

I. ***Was this a*** **Lab. Group_________** ***or a*** **Design Group_______*?***

Group meeting schedule:

	YES	NO
1. Did your group meet on a regular basis		

Positive Interdependence:

	YES	OCCASIONALLY	SELDOM	NEVER
2. Did your group discuss, and eventually agree on an answer and/or solution strategy for each problem?	100-75%	75-50%	50-25%	25-0%

	YES	SOME DID	A FEW DID	NO
3. Did each member of the group fulfill their assigned role / responsibilities?	100-75%	75-50%	50-25%	25-0%

Face-to-Face Promotive Interaction:

	YES	SOME DID	A FEW DID	NO
4. Did each member of the group share their knowledge with the rest of the group?	100-75%	75-50%	50-25%	25-0%

APPENDIX: 1 (Cont.)

Teamwork Skills:

	YES			NO
5. Did you or a member of your group take over *leadership* responsibilities?	100-75%	75-50%	50-25%	25-0%

	YES			NO
6. Were team *decisions* based upon discussion and consensus?	100-75%	75-50%	50-25%	25-0%

	YES			NO
7. Did the members of your team develop a *trust* in one another?	100-75%	75-50%	50-25%	25-0%

	YES			NO
8. Did each member of your group feel comfortable expressing their views and opinions?	100-75%	75-50%	50-25%	25-0%

	YES			NO
9. Did your team deal effectively with *conflict* and differences?	100-75%	75-50%	50-25%	25-0%

Group Processing:

	YES			NO
10. Did your group's discussions include topics focusing on teamwork skills, and collaborative skills? (see #5 thru #9 above)	100-75%	75-50%	50-25%	25-0%

Individual Accountability/Personal Responsibility:

11. List the members of your group, and indicate your perception of the ***percentage*** of contribution each member provided in the completion of your group project. Be sure to include ***YOUR OWN NAME.***

NOTE: Your *% contribution* column must total 100%

Your name______________________________ % Contribution______________

Name__________________________________ % Contribution______________

Name__________________________________ % Contribution______________

Name__________________________________ % Contribution______________

Name__________________________________ % Contribution______________

TOTAL = 100%

APPENDIX : 2

Date Received: _______________

Proposal Accepted: _______________
Chair's Signature

The College of New Jersey
Department of Engineering

Senior Project

Project Proposal

Title of Project: ____

Semester: ______________

Student	**Advisors**
Name (print): ________________________	**Primary (print):** ________________________
Contact Phone #: ____________________	**Collaborating:** ________________________
E-mail: ______________________________	

Group Members ____

Grade Weighting Criteria (%)

SP1		**SP2**	
Preliminary Design Report (40-70)	[ ]	Final Design Report (40-70)	[ ]
Preliminary Design Presentation (10-30)	[ ]	Final Design Presentation (10-30)	[ ]
Project Notebook (10-30)	[ ]	Project Notebook (10-30)	[ ]
Other Pertaining Criteria (10-30)	[ ]	Working Model (0-30)	[ ]
		Other Pertaining Criteria (10-30)	[ ]

Formulation and Statement of Design Problem:
(continue on a separate sheet as necessary)

Planned Approach to Design Activity:
Include proposed outcomes and deliverables
(continue on a separate sheet(s) as necessary)