

A Pilot Study of the Performance of Student Teams In Engineering Education

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Abstract

Teams are increasingly used in the professional world although a clear understanding of what is required to be a high performing team does not seem to exist. Many studies have identified characteristics that can improve performance; however not many studies have tested whether the existence of these characteristics determines a high performing team. The purpose of this study is to test whether seven team characteristics (productive conflict resolution, mature communication, role clarity, accountable interdependence, goal clarity, common purpose and psychological safety) can be used to predict team performance. Hypotheses were developed and tested for positive correlations between each of the seven constructs and team self-performance.

This paper and presentation will report the results of two studies conducted using the Team Performance Questionnaire (now referred to as the Teams Effectiveness Questionnaire) developed at the University of Nebraska-Lincoln (UNL). The first study was conducted on the UNL campus with senior engineering students. The second study was conducted as a web-based survey with students participating in E-Teams sponsored by the National Collegiate Inventors and Innovators Alliance. The statistical analysis produced significant results, which support the hypotheses and produced a predictive equation, which can be useful in forming teams in the future.

Introduction

“In the complex world of the next decade, teamwork is going to grow beyond its already high importance”.¹ “Many organizations are moving toward an internal structure based on work teams or groups rather than the traditional ranks of individual contributors”, and having workers with the proper training in these areas is an essential element for any organization’s success.² The escalating use of teams in industry and academia creates a need for a workforce with excellent communication and interpersonal skills, as well as an understanding of what it takes to be an effective team, but this growth also creates a number of unanswered questions about the inner workings of teams and the means to achieve and measure team effectiveness. Questions such as:

- 1) what does it mean to function on a multi-disciplinary team?
- 2) what should be used to measure students’ ability to do so?
- 3) how will teaming in the classroom be used to enhance this ability?
- 4) what role effect does teamwork have on the enhancement of learning?

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The answers to these questions are paramount if engineering educators are to successfully incorporate teams into the engineering classroom. To begin answering these questions, a new model of team effectiveness is under development at the University of Nebraska-Lincoln.

The Model for the Development and Facilitation of Effective Teaming, shown in Figure 1., is based on the following ideas:

- 1) individuals must understand and be able to demonstrate their understanding in areas leading to team effectiveness;
- 2) a collective team of individuals must also understand and be able to demonstrate their understanding in areas leading to team effectiveness; and
- 3) measurement of understanding must occur both individually and collectively prior to and at the conclusion of the task.

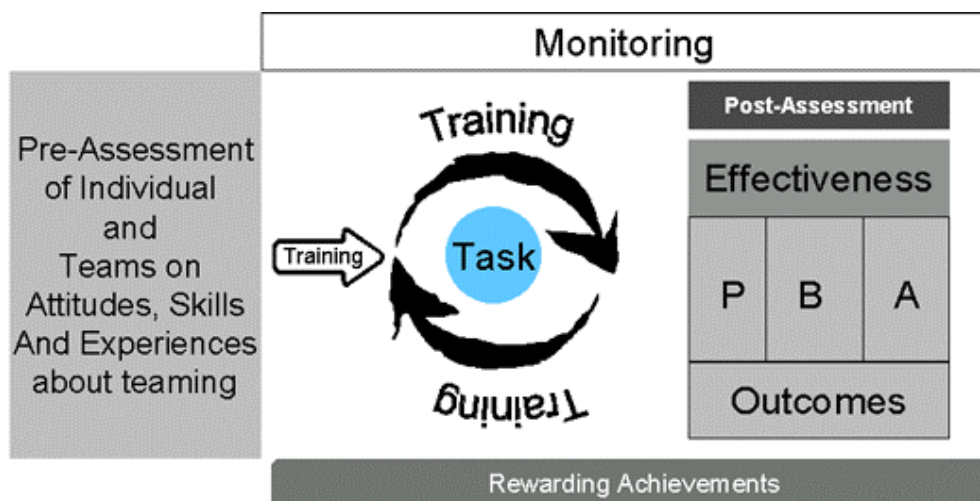


Figure 1. Model for the Development and Facilitation of Effective Teaming.

The goals for the academic use of the model depicted in Figure 1 are as follows:

- 1) to assist with the facilitation of teamwork in the classroom;
- 2) to assist with the measurement of individual growth to learning a subject and learning how to work in a team; and
- 3) to assist with the measurement of teamwork effectiveness in enhancing quality results.

The model starts with the assessment of the individual regarding their understanding of teams and their attitude toward teamwork, prior to starting the task and prior to any contact with fellow team members. The next step is the collective assessment of the team with regards to the teams' attitudes about teaming and the use of teams and the teams' ability to manage the seven constructs introduced here in the model. The objective of the pre-assessment phase is to provide a baseline to assist in measuring the growth of individuals and the growth of teams.

In this model, training and task performance are thought of as treatments and post-assessment is useful in measuring growth after the completion of the task. Once the task is

completed a post-assessment is to be conducted to measure the effectiveness of the team. Effectiveness will be measured using three outcomes: performance, behavior and attitude. These outcomes represent the specific areas that are being evaluated.

Performance considers the extent to which the outputs meet the standards of quantity, quality and timeliness of those who use the product or receive the service.³ Behavior considers the extent to which the team experience contributes to the growth and personal well being of team members.³ Attitude is concerned with examining how the process of carrying out the work enhances the capability of members to work together interdependently in the future.³ Table 1 shows what is being measured and how it will be measured for each outcome.

	Outcomes	Tool
Performance (P) (on the assigned task)	<ul style="list-style-type: none"> • Knowledge about the subject • Quality of the results • Timeliness • Quantity of the results • Skills mastery 	<ul style="list-style-type: none"> • Project report • Project presentation • Knowledge test (for declarative and procedural knowledge) • External assessment • Concept map • Vee diagram • Case studies
Behavior (B) (as a team)	<ul style="list-style-type: none"> • Behaviors identified with each of the construct contributing to team effectiveness 	<ul style="list-style-type: none"> • Direct observations • Interview • Video tapes
Attitude (A) (toward teamwork)	<ul style="list-style-type: none"> • Willingness of continuing working in team • Satisfaction for the teamwork experience and the work done 	<ul style="list-style-type: none"> • Questionnaire • Interview • Video tapes

Table 1. Outcomes of Model

In order to determine whether or not the students exhibit team characteristics, the following seven constructs were identified from the literature review and the work of leading theorists and practitioners in industry and academia, along with the personal experiences of the research team as contributors to a high performing teams. Furthermore, these constructs can be applied with a wide variety of teams and can be measured by asking team members for their attitudes, opinions, and perceptions. Brief definitions of each of these seven constructs are provided.

Common purpose is the main objective of the team, which should be understood and shared by all team members. Common purpose should lead to the development of the team’s goals. Successful teams shape their purposes in response to a demand or opportunity put in their path.⁴ This helps teams get started by broadly framing the convener’s expectation.

Clearly defined goals are quantifiable and commonly agreed upon statements that define the actions to be taken by the team. The attainment of specific goals helps teams maintain their focus.

Psychological safety is the shared belief that the team is safe for interpersonal risk taking.⁵ Psychological safety leads to a team climate characterized by interpersonal trust and mutual respect in which people are comfortable being themselves. Psychological safety is a sense of confidence that the team will not embarrass, reject or punish someone for speaking up.

Role clarity is the team members' common understanding of each individual's expected role. The presence of role clarity minimizes misunderstandings regarding task assignments.

Mature communication refers to team members' ability to:

1. articulate ideas clearly and concisely,
2. give compelling reasons for their ideas,
3. listen without interrupting,
4. clarify what others have said,
5. provide constructive feedback.

Mature communication among team members ensures a higher level of understanding.

Productive conflict resolution refers to the procedures and actions taken when a conflict occurs that lead to results such as:

1. facilitating the solution of the problem,
2. increasing the cohesiveness among team members,
3. exploring alternative positions,
4. increasing the involvement of everyone affected by the conflict and
5. enhancing the decision-making process.⁶

Accountable interdependence is the mutual dependence that all team members have regarding the quality and quantity of each individual's work within the team. Mutual dependence generates a shared sense of security.

Development of the model will occur in three phases. The first phase consists of the development of a questionnaire, the Team Effectiveness Questionnaire (TEQ). This instrument is used to measure performance and attitude and will be useful in addressing goal number 3, the measurement of teamwork effectiveness. The study presented here was designed to develop and test the TEQ with groups of engineering students. Future research will be conducted on the behavioral and attitude components of the model as well as the pursuit of goals 1 and 2.

Methodology

Although there are several commercially available questionnaires in the area of team performance and effectiveness the research team was unable to find evidence of any test based on the first build individuals and then build teams approach for which conclusive validity and reliability measures were reported. Based on this limitation of the commercially available tests,

these researchers decided to develop a new questionnaire based on the team effectiveness model being developed at this university and the available literature on this area.

The team effectiveness questionnaire was constructed using both nominal scales and interval scales. Nominal scales are used in the first part of the questionnaire to collect demographic information and some of the student preferences towards teaming. A five-point Likert scale ranging from “Strongly Agree” (1), to “Strongly Disagree” (5) is used as the interval scale for the second part of the questionnaire. Interval scales are used for most questionnaires for several reasons: variables measured in interval scales can be analyzed using parametric statistics which are based on the assumption that the scores represent a normal distribution around the population mean, and these scales also provide the most variation of responses lending themselves to better data analysis. Table 2 presents the questions used along with on the instrument along with the construct they measure.

The questionnaire developed was divided into two main parts. The first part was used to collect demographic data and information on individual preferences regarding teaming and previous team experiences. The second part of the questionnaire is used to measure the student’s ability to effectively work in teams and to measure their understanding of each of the characteristics identified by the team of researchers as vital for the performance of the team. Between five and nine questions were included in each of the categories.

The data for this study was collected from two samples. The first sample was comprised of senior engineering students at UNL enrolled in capstone courses during the Spring 2001 semester. Data from this sample was collected using a paper survey and was administered by the PI. The second study was conducted as a web-based survey with students participating in E-Teams sponsored by the National Collegiate Inventors and Innovators Alliance. Students participating in E-Teams worked on entrepreneurial projects similar to that of the senior design students at the UNL. The work of both samples can be characterized as “capstone design projects”. Students working on capstone designed projects were selected based on the premise that capstone projects enable students to work in an environment which minimizes the student’s dependence on the professor and prepare students for “real world” experiences.⁷

In developing a new instrument such as the TEQ it was important to explore the structure of the instrument. Kline suggests a ratio of 10 respondents per item is needed.⁸ Therefore the sample size would need to be in the neighborhood of 500. In order to increase the sample size pooling two samples can be useful. Therefore the data previously presented in the two samples was combined to increase the sample size, which will increase the stability of the instrument.

Several analyses were conducted to determine if the two samples were homogeneous and could be combined. The first analysis performed was a descriptive examination of the two samples. Demographic data such as gender, ethnicity and major were compared for both samples. Frequency and percentage data for both samples for gender, ethnicity and major are shown in Table 2. Although 20% of the students in the NCIIA sample indicated their majors were either business or science (i.e. Physics, Math or Chemistry) all students were enrolled in engineering courses where the main focus of their team was to solve a senior design problem.

Age data was unavailable due to a change in the wording of the question to accommodate the different data collection format.

13	Conflict	The team is able to resolve differences
14	Conflict	When we resolve a conflict, the team bonds (becomes closer)
15	Goals	Team goals are more than the sum of the individual goals
16	Role	I understand what my job entails within the team
17	Psych	It is safe to take a risk in this team
18	Purpose	Team members were committed to a common purpose
19	Role	What I thought I would be doing and what I actually do in the team are the same
20	Purpose	Team purpose and team goals were related
21	Inter	I believe I am a team player
22	Conflict	Managing conflict is a way to improve team performance
23	Psych/Commun	It is difficult to ask members of this team for help
24	Perform	This team's performance exceeds our expectations
25	Conflict	Disagreements are accepted and encouraged in the team
26	Commun	I listen to the other team members carefully
27	Goals	Accomplishing small goals helps the team stay focus
28	Psych	No one in this team would deliberately act in a way that undermines my efforts
29	Goals	The team goals emerged through team interactions
30	Role	Effective team leadership enhances the performance of the team
31	Commun	I can effectively communicate my ideas in a team
32	Conflict	Our team meetings are productive
33	Inter	We motivated each other when things were difficult
34	Goals	Team goals were challenging
35	Psych	People on this team sometimes reject others for being different
36	Perform	I am satisfied with the quality of my team experience
37	Goals	I clearly understood team goals
38	Commun	I feel comfortable communicating with team members of a different gender
39	Conflict	Conflict is always detrimental to get things done
40	Role	I clearly understand what is my role in the team
41	Goals	The team was committed to meet team goals
42	Purpose	I clearly understood the team purpose
43	Psych	Working in this team, my unique skills are utilized
44	Perform	I would like to continue working with this team in the future
45	Conflict	I agree with what people say so we can continue
46	Role/Inter	I do need help from other people in the team
47	Inter	Members of the team depend on me to get their tasks done
48	Purpose	Team members felt ownership of the team purpose
49	Perform	My experiences in the team will contribute to my career success
50	Inter	Each of the team members is responsible for the performance of the team
51	Commun	The team is always open to discussing ideas
52	Role	I understand clearly what other members duties are in the team
53	Commun	I receive valuable feedback from the team
54	Inter	The team members were enthusiastic about accomplishing the teams' goals
55	Inter	I can trust the other team members to do their part of the job
56	Purpose	The team purpose was developed by the team
57	Psych	If I make a mistake in this team, it will not be held against me
58	Psych	Working in this team, my unique skills are valued
59	Perform	This team keeps getting better and better
60	Commun	I feel comfortable communicating with team members of a different ethnicity/race
61	Psych/Conflict/Commun	Members of the team are able to bring up problems and tough issues
62	Commun	I feel comfortable asking for clarifications in the team if something is not clear

Table 2. Team Effectiveness Questions

	Sample I (UNL Senior Design Students)		Sample II (NCIIA E-Team Participants)	
	Frequency	Percentage	Frequency	Percentage
Gender				
Male	141	87	131	80.4
Female	21	13	32	19.6
Ethnicity				
Asian American	3	2	14	8.6
Black/African American	6	4	4	2.5
Hispanic/Latino/Mexican American	3	2	12	7.4
White/Caucasian	143	88	124	76.1
Other	6	4	9	5.5
Major				
Engineering	162	100	130	79.8
Business			20	12.3
Science			3	1.8
Other			10	6.1

Table 3. Demographic Data for Both Samples

The second analysis was to examine the frequency distribution for each item. Table 4 shows the distribution for item 13.

	Sample I (UNL Senior Design Students)		Sample II (NCIIA E-Team Participants)	
	Frequency	Percentage	Frequency	Percentage
Strongly Agree	63	38.9	43	26.4
Agree	89	54.9	89	54.6
Neutral	5	3.1	23	14.1
Disagree	5	3.1	7	4.3
Strongly Disagree			1	.6

Table 4. Response Comparisons for Item #13

The final analysis was to compare the means using an independent-samples t-test on the individual responses for each construct. The individual responses to each question for each construct were totaled and then compared to the same from each sample (e.g. Perform=Q24+Q36+Q44+Q49+Q59). At an $\alpha = .05$ two constructs, productive conflict resolution and psychological safety were the only two that were shown to be significant indicating the variances are not equal. Table 5 shows the results of the Levene’s Test for Equality of Variances.

		Levene's Test for Equality of Variances	
		F	Sig
Productive Conflict Resolution	Equal variances assumed Equal variances not assumed	4.735	.030
Mature Communication	Equal variances assumed Equal variances not assumed	.861	.354
Role Clarity	Equal variances assumed Equal variances not assumed	2.532	.113
Accountable Interdependent	Equal variances assumed Equal variances not assumed	.003	.958
Goal Clarity	Equal variances assumed Equal variances not assumed	.415	.520
Common Purpose	Equal variances assumed Equal variances not assumed	1.379	.241
Psychological Safety	Equal variances assumed Equal variances not assumed	7.180	.008
Performance	Equal variances assumed Equal variances not assumed	3.303	.070

Table 5. Levene's Test For Equality

The descriptive analysis, the examination of items and the results of the t-tests provide sufficient data for the researchers to feel comfortable in saying the two samples are homogeneous and can be pooled with caution.

Results

Participants

A total of 374 students completed the Team Effectiveness Questionnaire during the spring 2001 semester. Of this number 325 were usable and made up the sample size for the analysis presented here. According to the data collected, 19% of the subjects were female while the remaining 80% were males, while 78% of the participants were White/Caucasian. Ninety percent of the respondents were engineering majors.

Analysis

When developing questionnaires one must be concerned with reliability and validity. The only type of validity that can be reported for the team effectiveness questionnaire used in this study is content validity since. Content validity is the extent to which the questions on the instrument and the scores from these questions are representative of all the possible questions that could have been asked about the content or skills.

At this time, the only type of reliability that can be reported for the team effectiveness questionnaire is the internal consistency reliability with the Cronbach coefficient alpha calculated. The results from the reliability analysis are shown in Table 6.

Variable	Number of cases	Items	Alpha	Standardized item alpha
Conflict	315	8	.5076	.5892
Communication	309	9	.7799	.7969
Role Clarity	318	6	.6002	.6163
Interdependence	320	7	.5856	.6056
Goal	320	6	.7394	.7407
Purpose	319	5	.7311	.7374
Psychological Safety	316	8	.7193	.7271
Performance	320	5	.8049	.8075

Table 6. Instrument reliability (Cronbach’s Coefficient Alpha)

A factor analysis was performed to identify factors that statistically explain the variation and covariation among measures.⁹ Before the analysis was run, the researchers hypothesized high correlations between the constructs, and a correlation analysis was run to decide which rotation was adequate. In order to calculate the Pearson product moment correlation, new sets of variables were created compounding the scores of each of the constructs, and dividing by the number of questions added. The new variables are: teamperf (self-performance), teamconf (productive conflict resolution), teamcomm (mature communication), teamrole (role), teamacco (accountable interdependence), teamgoal (clearly defined goals), teampurp (purpose), teampsych (psychological safety).

As can be seen in Table 7, the results of the correlation analyses show that the 28 correlations were statistically significant ($p < .01$), and were greater than or equal to .5 indicating a very high correlation between the factors. The dimensionality of the seven constructs from the team effectiveness questionnaire was analyzed using principal components analysis and oblique rotation.

	Team Perf	Team Conf	Team Comm	Team Role	Team Acco	Team Goal	Team Purp
TeamConf	.715						

TeamRole	.611	.608					
TeamComm	.665	.631	.664				
TeamAcco	.718	.725	.656	.589			
TeamGoal	.698	.713	.691	.728	.671		
TeamPurp	.747	.698	.690	.643	.715	.781	
TeamPsych	.634	.546	.577	.789	.475	.598	.556

Table 7. Correlations among the constructs in the team effectiveness questionnaire

Multiple Regression Analysis

A multiple linear regression was conducted to evaluate how well the seven team constructs identified in the Team Effectiveness Questionnaire predicted team self-performance. The predictors were the seven team constructs identified in the model, while the criterion variable was the self-performance construct. The linear combination of team constructs was significantly related to team self-performance, $F(7,296) = 97.002$, $p = .0001$. The sample multiple correlation coefficient was .84, indicating that approximately 70% of the variance of team self-performance in the sample can be accounted for by the linear combination of the seven team constructs.

In Table 8, we present indices to indicate the relative strength of the seven individual predictors. All the bivariate correlations between the team constructs and team self-performance were positive as expected, and four of the seven indices were statistically significant, conflict ($p < .001$), interdependence/accountability ($p < .001$), purpose ($p < .001$) and psychological safety ($p < .001$). These results show that common purpose is the most useful predictor of team performance. Common purpose alone accounted for 56% ($.75^2 = .56$) of the variance of team performance, while the other three significant variables contributed only an additional 14% ($70\% - 56\% = 14\%$). The results of a multiple linear regression analysis show which characteristics could predict team performance. Using stepwise procedure in linear regression the model that best fit (69%) the data is:

$$\text{Performance} = -3.913 + .406 * \text{purpose} + .201 * \text{conflict} + .267 * \text{interdependence} + .206 * \text{psychological safety}$$

Team self-assessed performance can therefore be expressed as a function of a clear purpose, productive conflict resolution, interdependence and psychological safety.

Predictors	Correlation between each predictor and team self-performance
Conflict	.72 ***
Goal	.70
Role	.61
Psychological Safety	.63 ***
Purpose	.75 ***
Interdependence/Accountability	.72 ***
Communication	.67

* $p < .01$, ** $p < .05$, *** $p < .001$

Table 8. Bivariate and partial correlations of the predictors with team self-performance

Conclusions

This study presents the results of the first phase of development of a model for the development and facilitations of teaming in the educational arena, and specifically in the engineering classroom. The difference between the model we are presenting and the available models in the literature rests in the fact that our model looks at both the team's output and the process of getting the work done, not only the quantity of the team's output.

The Team Effectiveness Questionnaire was developed by researchers at the University of Nebraska-Lincoln to measure students' performance and subsequently attitude on each of the seven constructs identified (productive conflict resolution, mature communication, role clarity, accountable interdependence, clearly defined goals, common purpose and psychological safety), and their relationship to self-assessed performance.

Using the data collected from the questionnaire, several analyses were performed. The first analysis included internal reliability analysis of the items in the questionnaire using the Cronbach's coefficient alpha approach. The self-performance items presented the highest internal reliability with a standardized alpha equal to 81%, while conflict presented a very low reliability. The remaining reliabilities ranged from 60% for interdependence to 80% for communication. The results from the Pearson-product moment correlation analysis indicate high positive correlations between self-assessed performance and the seven constructs identified in the team effectiveness model being tested.

Based on the results obtained in the study, the minimum requirements to form a high performing team are the existence of interdependence among team members, the ability of members to resolve conflict, an environment that allows members to take risks, and the development of a clear team purpose set by the team. The existence of these characteristics paired with proper training throughout the team process will likely increase the performance of a team in the engineering classroom.

Since the use of teams is increasing rapidly, educators must provide students with the appropriate tools to work in teams, and the appropriate tools cannot be identified unless there is a clear understanding of what it takes for a team to be effective. This research tries to explain what it takes to be an effective team and it focuses on both the final teamwork result and the process of getting the work done, emphasizing individual and team pre- and post-assessment, as well as continuous training and monitoring for the team.

A concern of this initial study was the sample size and the factor loading when conducting a factor analysis. Unfortunately the items did not load in the factors as expected, and the main limitation is the research sample. In any factor analysis and any research study, there are two important issues with the sample: the type of respondents and the size of the sample.¹² Any analysis is enhanced if the sample has a wide variety of people. In this case, there was not much diversity in the sample since most respondents were male, Caucasian, traditional college aged, engineering students. The second issue was the sample size. The sample size required for

a stable factor analysis is usually given as a function of the number of items being tested (generally 10 cases for every item). In the case of this study, and based on the final number of items being tested, a larger number of respondents would be required to obtain a stable factor loading, therefore further testing of the questionnaire can attempt to fulfill this gap.

The research team is hopeful that with additional research this work will provide answers to the questions previously stated and fulfillment of the goals of assisting with the facilitation of teamwork in the classroom; measurement of individual growth to learning an subject and learning how to work in teams; and measurement of teamwork effectiveness.

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