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Methodology and Metrics for Assessing Team Effectiveness*

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This paper describes a new systematic methodology and measurements for assessing the effectiveness of engineering/business student teams. This new methodology is unique because it predicts team effectiveness. Our approach replaces the traditional methods of indirect surveying and interviewing with direct surveys and systematic exercises designed to measure team effectiveness. Effectiveness was defined and evaluated using three outcomes: creativity, collaboration and productivity. These three outcomes were measured using applied psychology metrics. By quantifying creativity, collaboration and productivity, this new assessment methodology provided a more objective way of measuring effectiveness. The outcomes were equally weighted to calculate an effectiveness rating. The teams that were faculty-selected and properly coached were confirmed to be at least twice as effective as those that were student-selected and received little coaching.

INTRODUCTION

A TEAM is defined as a 'small number of people with *complementary skills* . . .' [1]. In this definition, *complementary skills* refers to a team with multidisciplinary skills, for example, design, marketing and manufacturing, not different engineering disciplines. Multidisciplinary teaming is important for developing industrial products [2], and teambuilding skills are important because at least two-thirds of US enterprises solve problems using teams [3]. More recently, teambuilding has become a requirement for engineering accreditation by the Accrediting Board for Engineering and Technology (ABET). One of ABET's program outcomes in *Engineering Criteria 2000* has stated that 'engineering graduates must have an ability to function on multidisciplinary teams' [4]. EC 2000 implies that engineering graduates must function 'effectively' on teams. What does the term 'effectively' mean?

In a recent paper, Adams [5] has repeatedly used the phrase 'effective teams,' but this term has not been defined. In addition the outcomes characterizing effectiveness were not specified. University of Pittsburgh has most recently attempted to define the characteristics of effective teams [6]. There are two primary issues in defining team effectiveness: the methodology used to assess it, and the metrics used in measuring it. Nowhere in our literature search was there a clear definition of effectiveness [4, 5, 7] or how to develop effective teams using a systematic methodology. Many investigators have used surveying and interviewing methods to identify the factors of effective teams [5, 7, 8], like co-locating the team members, or having cross-functional team members [7]. However, there has been no systematic process to assess team effectiveness.

The term 'metrics' consists of the performance criteria and rating scale for measuring effectiveness [9]. To our knowledge, there have been no performance criteria or values for measuring team effectiveness. Many of the investigators have discussed some of the factors that contribute to effectiveness [5–8]. However, there has been no direct measurement of team effectiveness.

The purpose of this paper is to describe a new systematic methodology which defines, assesses team effectiveness. Our methodology will use applied psychology metrics to measure team effectiveness. We will utilize published assessment terminology [4, 9] and will adapt the process that has been used for outcomes assessment under EC 2000 [10]. We will conduct experiments that will directly measure team effectiveness.

BACKGROUND

The traditional methods of measuring effectiveness were by indirect surveys and interviews without properly controlling the participants. In a national survey conducted on $\sim 90\%$ engineering students, Adams [5] reported that training of single disciplinary teams did not have much impact on the students' effectiveness; although it is not clear what was her definition of effectiveness. Since Adams' results originated from student opinion surveys, the results were biased toward single disciplinary teams. Based on interviews with teams from the Department of Defense and commercial firms for the development of weapon systems, the Government Administrative Office (GAO) has recently reported on the factors that contribute to effective teaming [7]. Although these results did not yield a clear definition of effective

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teams, several factors were identified. Realizing the lack of a clear definition of team effectiveness, University of Pittsburgh has recently conducted surveys of institutions that use entrepreneurial teams in order to define 'effective teams' [6]. However, this survey measures the faculty's response to the factors that contribute to team effectiveness.

LMU's Engineering and Production Management (EAPM) graduate program has established an assessment method for measuring non-technical (subjective) outcomes [11], such as team effectiveness. This has been conducted on teams of engineering and business graduate students to measure their effectiveness in teams during various courses. This method has been combined with the process of outcomes assessment to determine team effectiveness, as discussed below.

Inputs and outcomes assessment

The outcomes assessment plan is combined with our abridged assessment process in Mechanical Engineering [10]. In the present work, our assessment plan was driven by our constituents' needs—team invention and innovative problem solving [12]. These needs were linked with our educational objective, that is, the ability to work effectively in entrepreneurial teams. This educational objective was consistent with both the mission of LMU and our EAPM graduate program. Our outcomes were established such that they would link with (1) our educational objective, (2) our learning objectives in our course syllabi, and (3) our coaching inputs that were taught in the classroom. The process is diagrammed in Fig. 1, and the links are shown in gray-colored boxes.

The coaching inputs were the faculty's teaching, and our outputs (outcomes) for our courses were student learning. The faculty's inputs were teaching teambuilding, communication and innovation in the classroom environment. Based on our educational objective (entrepreneurial effective teams) and three learning objectives, the results of our outcomes for effective teams were chosen to be creativity, collaboration and productivity (Fig. 1). The rationale for selecting creativity, collaboration and productivity was that it satisfied our constituents needs—creative problem solvers, team collaborators and productive workers.

Our three outcomes were general enough to correlate with previous published work on teambuilding. For example, they were directly correlated with the essential non-technical skills for teams [13, 14]. In a recent publication by the General Accounting Office (GAO), effective teams have been shown to have at least nine traits [7]. The relationship between these nine traits and our three outcomes are shown in the dot-matrix diagram of Table 1.

The results show that the GAO's nine traits of effective teams were directly related to our three outcomes. Here, creativity and collaboration relate more to the nine factors of effective teams than productivity. These examples indicated that our chosen outcomes were realistic and practical for characterizing team effectiveness.

Hence, we have defined effective teams in terms of their outcomes (creativity, collaboration and productivity) and shown in Fig. 1 the process by which they can be assessed. These outcomes were realistic because they related to the previous published factors for effective teams.

TERMINOLOGY AND ASSUMPTIONS

In order to measure the effectiveness of teams, it is important to carefully define our terminology and assumptions. The basic definitions of integrated, multidisciplinary, diversity, compatibility, creativity, collaboration and productivity are

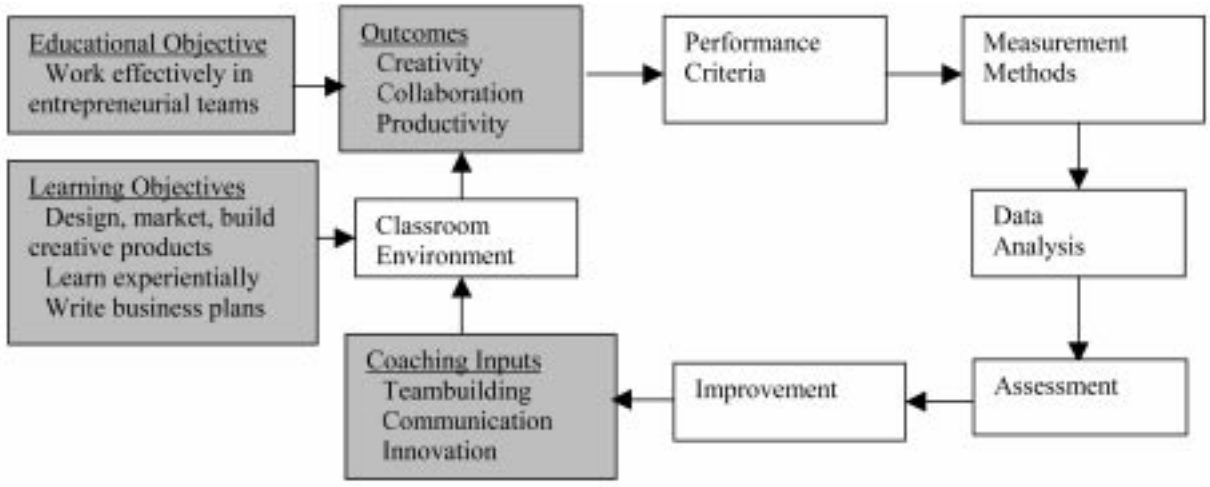

Fig. 1. Outcomes assessment plan (gray colored) combined with LMU's Mechanical Engineering assessment process [10].

Table 1. Relationship matrix: traits of effective teams vs. outcomes.

Traits of Effective Teams	Outcomes		
	Creativity	Collaboration	Productivity
1. Co-location	•	•	
2. Commitment	•	•	•
3. Multidisciplinary	•	•	
4. Decision authority		•	•
5. Productive environment	•	•	•
6. Training	•	•	
7. Accountability		•	•
8. Leader-selected with team member preference	•	•	
9. Immediate feedback		•	

shown in Table 2. Table 2 is organized in such a way that basic terms are first defined, and then terms requiring these definitions are next defined. Here, integrated teams are distinguished from multidisciplinary teams by the fact that integrated team members are compatible with each other due to the faculty's coaching inputs (Fig. 1). 'Fully integrated' means that the outcomes of effectiveness (collaboration, creativity and productivity) are combined harmoniously with a complete set of metrics, where the outcomes are weighted equally which implies the team is balanced. On the other hand, a non-integrated team typically does not work well together because it is unbalanced with respect to creativity, communication and productivity.

HYPOTHESES

Without a systematic methodology to measure effectiveness, it is unclear how much improvement can be predicted. In our work, we will take qualitative findings such as those by GAO a step further by quantitatively measuring the effectiveness of two hypotheses. GAO concluded qualitatively that integrated teams were more effective than non-integrated teams. In our first hypothesis, we will attempt to predict the percentage effectiveness of partially integrated, multidisciplinary teams over non-integrated, single disciplinary teams. Once proven, the first hypothesis will demonstrate that the new systematic methodology presented herein is realistic, since it predicts results which are qualitatively self-evident and which are consistent with previous findings [7]. In our second hypothesis, we will predict the percentage effectiveness of diverse teams over student-selected teams.

The two hypotheses that we are attempting to predict from our experiments are as follows:

- *Hypothesis I:* Partially integrated, multidisciplinary teams of students are more effective than non-integrated, single-disciplinary teams.
- *Hypothesis II:* Fully integrated, multidisciplinary, diverse teams are at least twice as effective as non-integrated, single-disciplinary, student-selected teams.

If hypothesis I is proven, then hypothesis II will compare how much more effective are faculty-selected (diverse) teams over student-selected teams. If these two hypotheses are proven, it can be predicted how effective are integrated, multidisciplinary, diverse teams over the benchmarked teams. In this case, we assume to a first approximation that there are no interactions between the factors (integrated, multidisciplinary and diverse].

Table 2. Definitions and examples of terms.

Terms	Definition	Example
Integrated	Harmonious (compatible) interrelationships [15] that are enhanced by coaching inputs (see Fig. 1).	A successful marriage or a symphony orchestra, playing in harmony.
Multidisciplinary	Having cross-functionality, whose primary functions and capabilities are different [16].	Team consisting of design, marketing and manufacturing skills
Compatibility	Working in harmony with each other and having the ability to resolve conflicts [16].	Self-directed team that can achieve consensus. Successful athletic team.
Diverse (team)	Team of 'compatible opposites:' Compatible as a group; yet opposite in terms of their ethnicity/gender, thinking and motivation [16]. Selected by faculty.	Compatible husband and wife team.
Creativity	Looking at established structures in new and different ways [17].	Seeing many solutions to a specific problem.
Collaboration	Open and clear dialogue—both verbal and non-verbal, including active listening [16]	Spontaneous conversation with relaxed body language that is consistent with what is said.
Productivity	Complete and accurate assignments that are submitted on time.	High quality report completed before the end of the course.

EXPERIMENTAL PROCEDURE

Course teams

Graduate engineering and business students were formed into teams from our two-semester courses: New Product Development (NPD) and Entrepreneurship graduate courses. These courses have been previously described, and our coaching methods have been reported. These courses were co-taught by faculty from engineering and applied psychology (LMU's Engineering and Production Management graduate program) and business (LMU's MBA program). The courses emphasized marketing, design, building prototypes and writing business plans for developing innovative products [18]. In our current paper, we use the term 'coaching' rather than 'teaching,' because coaching fostered a supportive environment in the classroom, which promoted team integration [18]. In the six years that the New Product Development (NPD) course has been taught, we anecdotally noticed that the methods of coaching teams were correlated with their effectiveness. In order to objectively confirm this, the hypotheses were designed to compare the teams in the NPD course with those in the Entrepreneurship course.

The teams were selected differently in the two courses. In the NPD course, the faculty first selected the teams; then the teams subsequently selected their own product concepts. The teams of engineering and business students were chosen based upon the:

- direct surveys of the students' capabilities, right/left-brain thinking [19], motivation and ethnicity/gender;
- exercise on the students' spatial compatibility.

More detailed information about the type and characteristics of these teams, as well as samples of the generic direct surveys and a spatial exercise for non-verbal compatibility are included in the Tables A1–A2 (see Appendix).

Direct surveys were used to determine the preliminary grouping of the students in teams according to their attributes. The survey on student capabilities/knowledge was designed to establish the students' skills in four disciplines: marketing/business, computer-aided design, prototyping and communication. The students rated themselves (strong ability, knowledgeable, some knowledge, weak) in each discipline and were tentatively grouped according to their highest ability [8]. Then their grouping was modified to achieve a distribution of right- and left-brain thinkers and students who were motivated by creativity on each team. Their grouping was further modified to ensure ethnic/gender diversity. The direct surveys assisted the faculty in forming balanced teams. However, the final teams were selected after the students' compatibility was determined from exercises. The goal was to select teams who were 'spatial compatible opposites'.

Throghout the semester, various exercises were used to determine the students' compatibility through teambuilding and spatial compatibility exercises. The typical teambuilding exercises have previously been described [18]. Spatial compatibility was determined by measuring the distance of the comfort zone between pairs of interacting students. When the inner distance of one student was within the outer distance of the interacting student, the students were predicted to be compatible; and when the inner distance of one student was greater than the outer distance of the interacting student, the students were predicted to be incompatible. Teams of 3 to 4 students each were selected and coached extensively throughout the NPD course to improve their teamwork [18]. The effectiveness of the NPD teams was observed about 14 times throughout the semester to confirm that the teams were compatible.

In the Entreprenerurship course, the teams were randomly selected around the students' product-preference, despite the fact that the randomly selected teams were unbalanced, due to their lack of diversity. The students first presented their product concepts in the classroom. Then the teams were formed around the students' preference to the proposed product concepts. Five teams of 2 to 7 students each were formed. Two of these teams were multidisciplinary, and the other three teams consisted only of business students. In all cases, these teams had infrequent coaching in teambuilding, communication and innovation, which made them partially integrated (Table 2). The teams' effectiveness in the entrepreneurship course was measured about 7 times throughout the semester.

In our two courses, the teams were instructed differently in relation to our coaching inputs—teambuilding, communication and innovation (Fig. 1). These differences are briefly described in Table 3 and summarized below. The coaching differences primarily arose in establishing team norms, providing communication exercises and immediate feedback, having innovation exercises [18], and in de-emphasizing course grades [20]. During teambuilding, the methodology of establishing team norms (such as goal setting, establishing roles and responsibilities, building consensus, and making team decisions) [16] was emphasized more frequently in NPD than in Entrepreneurship. In addition, the faculty selected the teams in NPD, and the students selected their own teams in Entrepreneurship.

In communication, more group exercises (communication training, improvisation, role playing and conflict resolution) and team feedback were performed more frequently in NPD than in Entrepreneurship. In NPD, both verbal and non-verbal feedback were given frequently to the teams; whereas in Entrepreneurship, only written feedback was infrequently given.

As far as the innovation environment was concerned in NPD, experiential exercises such as

Table 3. Comparison of coaching inputs between the two courses.

Coaching inputs		New Product Development	Entrepreneurship
Teambuilding Environment	Establishing norms (operating guidelines)	Team selection, goals, roles and responsibilities, rotating leadership, consensus, and decision making.	Done infrequently. Teams selected according to product preference.
	Resources	Team budget	No team budget
Communication Environment	Exercises	Group training [16], improvisation, role playing and conflict resolution.	Done infrequently.
	Team feedback	Immediate: verbal and non-verbal feedback.	Infrequent: mainly written feedback.
Innovation Environment	Exercises	Brainstorming, sketching, training games, Play-doh^{R} prototypes, and problem solving [18].	Infrequent: emphasized course content.
	Atmosphere	Relaxed, stress-free, taking risks, and accepting mistakes as learning [18].	Taking risks, accepting mistakes as learning.
	Grades	De-emphasized.	Emphasized.

brainstorming, problem solving, and sketching were performed frequently. In Entrepreneurship, innovation was based primarily on the creative traits of entrepreneurs. Hence, there was significantly more coaching in the New Product Development course than in the Entrepreneurship course.

In both courses, the teams had certain similarities in their teambuilding and innovation environment. Both courses had co-located teams, and the teams had the authority to fire 'free-loaders,' that is, students who were not carrying their fair-share of the work. The teams were encouraged to take risks and to make mistakes, and the teams would not be penalized for making mistakes, because making mistakes was considered to be a learning experience [18].

Methods and metrics

In order to measure our outcomes, we utilized applied psychology metrics. After the outcomes were developed, the performance criteria (specific indicators that measured the outcomes) were established [9]. The performance criteria also had to be divided into more specific sub-levels, which were used to create the metrics for measuring our outcomes. The performance criteria that we selected were the physical (P), emotional (E), mental (M) and energy (E) levels. To our knowledge, this was the first application of these criteria for measuring team effectiveness.

The PEME levels have previously been reported to be relevant performance criteria in applied psychology [21–24]. However, for the most part, they have been largely ignored in the engineering education literature. In industrial psychology, Maslow [25] related the physical, emotional, mental and energy levels to a person's state-of-being. Goleman [26] mentioned that a person's state-of-being was related to both emotional and intelligence components. His emotional component consisted of both the physical and emotional levels, and the intelligence component consisted of both the mental and energy levels. The energy level has been detected in an electromagnetic spectrum emanating from a person [27]. Hence, the PEME levels were reasonable performance criteria.

The goal of our methodology was to measure team progress. The feedback on team progress was measured by the effectiveness rating of our outcomes—creativity, collaboration and productivity, which were divided into the PEME levels, sub-levels and metrics. Table 4 provides an overall roadmap of our outcomes at different PEME levels, which should be used for navigating the reader through our methodology. For example, in Table 4 the physical level is divided into non-verbal and verbal sub-levels. The sub-levels are spatial distance, visual, facial expression, body posture, vocal sound and verbal expression.

The metric in Table 4 was used for measuring the creativity, collaboration and productivity outcomes. For example, if we are interested in measuring creativity or collaboration at the P-level and visual sub-level, then eye contact and blink frequency were the metrics that were used. Some of these metrics in Table 4 were subjective. Likewise, productivity at the P-level was measured by the quality of the teams' work, which was defined as the thoroughness and accuracy in completing their assignments and submitting them on time. Examples of the teams' work included creative product designs and prototypes, creative marketing and business plans. Since the quality of the teams' work was dependent on the creative tasks, the productivity outcome was correlated with creativity. The metrics that we selected were quick and easy to use in our courses. However, they were not the only metrics that could be used for measuring effectiveness.

Each of the metrics in Table 4 had a rating scale that ranged from 1 (low) to 9 (high). A low rating (1 or 2) was characteristic of strongly passive or aggressive behavior [28], which meant the team environment was harmful to creativity and collaboration. If a team had this low rating, then it was coached on how to overcome the behavior. If the team was unable to raise its rating after several

Table 4. Map of 'effectiveness' outcomes vs. PEME levels.

	Effectiveness outcomes			
PEME Levels	Sub-Levels	Creativity	Collaboration	Productivity
Physical (P)	Spatial distance	Spatial separation	Spatial separation	
	Visual	Eye contact Blink frequency	Eye contact Blink frequency	Thoroughness
	Facial expression	Facial expressions (frown/smile)	Facial expressions (frown/smile)	Accuracy
	Body posture	Open or closed	Open or closed	
	Vocal sound	Volume (loud/soft) Pace (fast/slow)	Volume (loud/soft) Pace (fast/slow)	Timeliness
	Verbal expression	Statements expressed as 'I,' 'You' or 'We'	Statements expressed as 'I,' 'You' or 'We'	
Emotional (E)		Clarity of objectives Being playful and taking risks	Feelings (stressed or pleasant) Intensity of over-reaction	
Mental (M)		Flexible thinking	Thought (stressed or pleasant) Clarity of thinking	
Energy (E)		Intuitive and imaginative	Connection with self and others Energy intensity	

weeks, then it was considered to be incompatible. In this case, on a P-level/spatial sub-level, there was little team harmony. Here the team members were spaced either very close to each other (typically < 0.3 m, aggressive behavior) or very distant from each other (typically > 1.5 m, passive behavior).

A rating from 3 to 7 was characteristic of either moderately passive or moderately aggressive behavior, which meant the environment was uncomfortable for creativity and collaboration. Here, more of the team members were spaced at less extreme distances from each other. A low medium rating of 3 or 4 was characterized by a distance of 0.3–0.4 m (aggressive behavior) or 1.3–1.5 m (passive behavior). Likewise, a medium rating of 5 was characterized by a distance of either 0.4–0.5 m (aggressive behavior) or 1.2–1.3 m (passive behavior). A high-medium rating of 6 to 7 was a distance of either 0.5—0.6 m (aggressive behavior) or 1.1–1.2 m (passive behavior).

A high rating (8 or 9) was considered assertive behavior, which meant the environment was very comfortable for creativity and collaboration. Here almost all of the team members were spaced at a relaxed distance from each other, typically between 0.6–1.1 m. The creativity and collaboration outcomes were intended to reflect the environment, rather than the corresponding team productivity.

An effectiveness rating was calculated for each team, from the mean of the creativity, collaboration and productivity measurements, which were weighted equally. The verbal and non-verbal expressions of the team (Table 4) were measured to obtain individual ratings for each outcome; then these ratings were averaged to obtain overall effectiveness rating. For example, on the physical level a spatial rating of 2 might be assigned to a team if the members were either spaced <0.3 m or farther apart than >1.5 m. If visual, facial, body posture, vocal and verbal expressions were equally aggressive or passive (each with a rating of 2), then the overall physical rating would be 2. If the team was taking some risks, the emotional rating of creativity would be 4. High risk-taking is correlated with the team's willingness to take on challenge, which would be an 8 or 9 rating. Taking no risks is correlated with a 1 or 2 rating.

If the mental and energetic levels of creativity were rated as a 2 and 4, respectively, then the effectiveness with respect to creativity would be a 3 (mean of $P = 2$, $E = 4$, $M = 2$, $E = 4$). If the ratings for communication and productivity were 4 and 5, respectively, then the mean effectiveness for our outcomes would be rated at 4. If an effectiveness rating of 8 was desired, then significant coaching inputs would be required, such as different team selection, co-located meetings, or a different classroom seating arrangement.

Both of our hypotheses were previously stated in terms their alternative hypothesis. The null hypothesis was evaluated as an equality statement, where the difference between the mean of two populations was equal to a specific value (Δ_o) for one sided t-testing [29]. For example, in Hypothesis I, if the difference between the mean of the population for integrated, multidisciplinary teams (μ_2) and that for non-integrated, single-disciplinary teams (μ_1) is a specified percentage (Δ_o/μ_1), then the alternative hypothesis is accepted if $(\mu_2 - \mu_1)/\mu_1 > \Delta_o/\mu_1$. Sequential hypothesis testing was performed by increasing the Δ_o/μ_1 percentage in order to determine the boundary of the critical region where the null hypothesis could be accepted. This permitted the percent effectiveness, Δ_o/μ_1, of the two Hypotheses I and II to be calculated. A 5% level of significance and unequal variances for the two sets of sampled data were assumed.

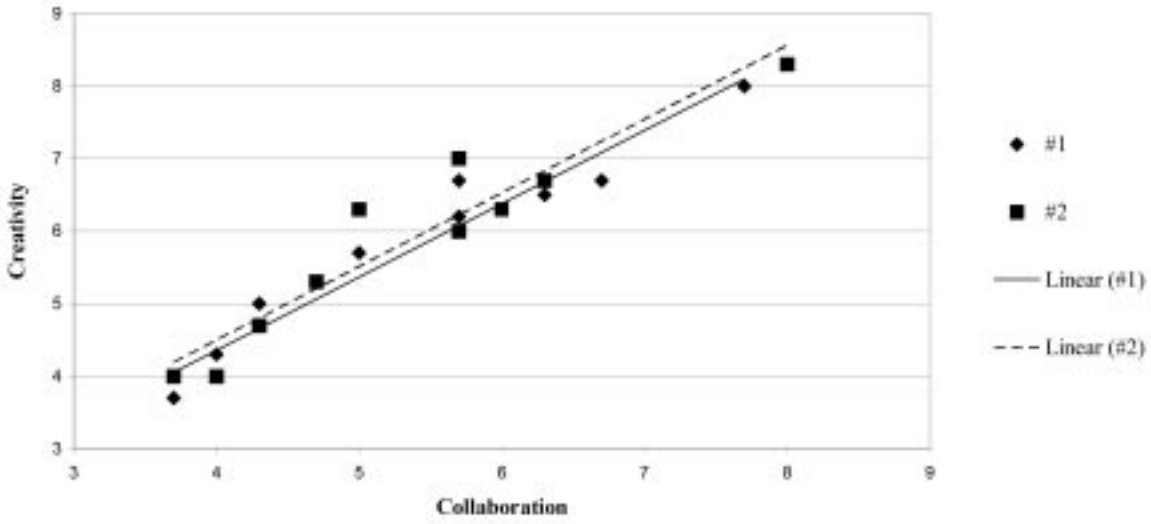

Fig. 2. Correlation of Creativity vs. Collaboration in New Product Development course for Teams #1 and #2.

RESULTS AND DISCUSSION

Creativity vs. collaboration

Since effectiveness was the mean of the creativity, collaboration and productivity ratings, it was important to know the correlation between these outcomes in order to understand the interaction between any two of the variables. The interactions between creativity/productivity and collaboration/productivity were expected to be significant [1, 16]. However, these were not measured, because the interaction between creativity and collaboration was qualitatively expected to be much greater. The measurements of creativity vs. time (by week) and collaboration vs. time (by week) throughout the semester have been reported to have increased [18]. From these measurements, it was possible to directly correlate creativity with collaboration. In this case, the measurements from our emotional, mental and energy levels (Table 4) for creativity vs. collaboration were analyzed. Since the P-level metrics were the same for creativity and collaboration (Table 4), these ratings were omitted from the correlation. From limited measurements on two teams in our NPD course, the results are shown in Fig. 2. Here, least squares lines were fit to the data for both teams. The statistical correlation coefficients were determined to be 0.97 and 0.95 for Teams #1 and #2, respectively, which meant that team creativity was strongly correlated with team collaboration. We have also observed this correlation over a two-year period in both courses when the students were asked: 'What are you doing when you are most creative?' [18].

Qualitatively creativity and collaboration were expected to be correlated, because a team that collaborates well usually conceives a high quantity of ideas during brainstorming [16]. However, to our knowledge, the relationship between creativity and collaboration has never been statistically correlated for teams. We have also observed that conflicts among the team members have inhibited the team's creativity. When the conflicts were resolved, the team members communicated more clearly and openly, and the teams generated more creative ideas. The team members were more willing to take risks and make mistakes. In addition, the teams unleashed more creativity when they were in a relaxed, stress-free classroom environment, and this occurred when they had an open and clear dialogue. We have observed that stress could be reduced by de-emphasizing grades and getting the teams to accept mistakes as a learning experience. The elimination of grades in higher education has also been suggested by Deming [20].

Hence, our findings showed that creativity and collaboration were strongly correlated, because clear and open communication was necessary to unleash team creativity.

Outcomes assessment

The effectiveness rating was compared for the different teams in both courses as a function of time. The two integrated, multidisciplinary, diverse teams from our New Product Development (NPD) course were denoted as Teams #1, 2. The two partially integrated/multidisciplinary, diverse teams from our Entrepreneurship course that had students from our previous NPD course were Teams #3, 4. The remaining three single-disciplinary teams of business students in the Entrepreneurship course were Teams #5–7.

The effectiveness rating of Teams #1, 2 and Teams #3, 4 significantly increased with time throughout the semester. The effectiveness rating of Teams #5–7 did not significantly change with time. The data on the effectiveness rating of all seven teams are plotted in Fig. 3 in relation to their creativity, collaboration and productivity. These data were measured at the completion of the courses, except for creativity in Entrepreneurship Teams #3–7, which was inadvertently omitted. Here the creativity rating was taken to be the

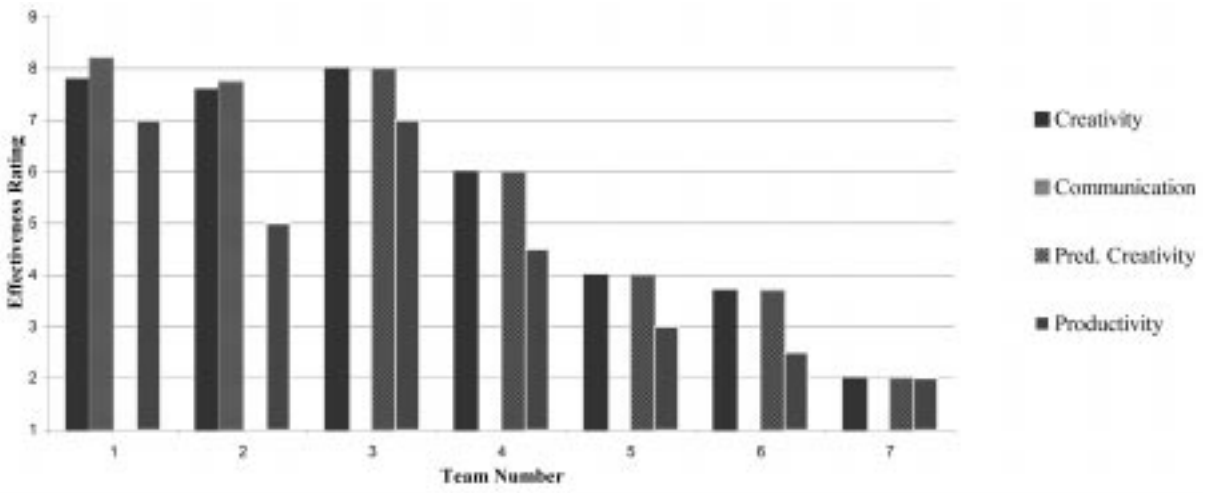

Fig. 3. Effectiveness rating vs. team No. in New Product Development (#1, 2) and Entrepreneurship (#3–7) Courses.

same as the collaboration rating (Fig. 2). Hence, 'predicted creativity' was used to replace measured creativity in Fig. 3 for Teams #3–7.

Using the sampled data from Fig. 3, Hypotheses I and II were analyzed. The mean of the sampled data for partially integrated, multidisciplinary teams (#1–4) was 131% greater than that for non-integrated, single-disciplinary teams (#5–7). In order to statistically verify this sampling, the sampled data was evaluated in Table 5. For example, a null hypothesis (percentage difference in populations means) of 80% is rejected, because it exceeded the boundary of the critical region. When the percentage difference in population means was at least 85%, the null hypothesis is accepted with 5% error. As a consequence, the teams were at least 85% more effective when they were partially integrated and multidisciplinary than when they were non-integrated and single disciplinary.

The mean sampled data in Fig. 3 indicated that fully integrated, multidisciplinary, diverse teams (#1, 2) were 142% more effective than teams (#5–7), which did not have these attributes. In Table 5, Hypothesis II is proven when the boundary of critical region is reached, whereby the effectiveness of fully integrated, multidisciplinary, diverse teams was at least 96% greater than that for non-integrated, single-disciplinary, student-selected (non-diverse) teams. These results substantiated Hypothesis II that compatible, cross-functional, faculty-selected teams, which were properly coached, were at least twice as effective as teams that did not have these attributes.

Our findings indicated that multidisciplinary teams were necessary, but not sufficient for being effective. Effective teams also needed to be both diverse in their ethnicity/gender, thinking, motivation, and they needed to be integrated by supportive coaching in teambuilding, communication and innovation.

From the sampled data in Fig. 3, it also could be shown that an intermediate case between Hypotheses I and II can be proven. The effectiveness of fully integrated, multidisciplinary, diverse teams (#1, 2) was at least 16% greater than that for partially integrated/multidisciplinary/diverse teams (#3–7). This low effectiveness difference was due to the high variance of the data for Teams #3–7 (Fig. 3), because the Entrepreneurship Teams #3, 4 contained some students from our previous New Product Development course. Assuming that there was no interaction between the variables in the two hypotheses, our findings have shown that fully integrated teams were at least 16% more effective than partially integrated teams. The more integrated a team, the more effective was that team. This was achieved through coaching by establishing norms, practicing communication (such as conflict resolution), giving immediate team feedback, providing team resources, exercising creative problem solving, and having a relaxed classroom atmosphere that encourage risk-taking.

In our work, we directly measured team effectiveness through classroom exercises in controlled groups of students. Our results have unequivocally confirmed that team effectiveness can be significantly improved when the teams were properly selected by the faculty and properly coached in teambuilding, innovation and communication.

Table 5. Hypothesis testing [29] of teams from Fig. 3

Null hypothesis (H_o: Δ_o/μ_1)	t-statistic (calculated)	$t_{.05,\ v}$ (table)	Accept or reject H_o	Critical region to accept H_o	Sample mean difference
Hypothesis I: 80%	2.12	1.90	Reject	85%	131%
Hypothesis II: 90%	2.30	2.02	Reject	96%	142%

CONCLUSIONS

LMU's Engineering and Production Management graduate program offered two team courses: New Product Development and Entrepreneurship. The courses were co-taught by faculty from engineering, business and applied psychology. The outcomes of effectiveness were creativity, team collaboration and productivity. These outcomes were directly measured and assessed; and team effectiveness was improved by a factor of ~ 2 when our team selection method and coaching inputs were implemented. The results of our work were as follows:

1. Creativity and collaboration were strongly correlated.
2. Multidisciplinary teams were necessary, but not sufficient for being effective. Effective teams also needed to be both integrated and diverse.
3. Integrated teams had enhanced creative, collaborative, and productive outcomes that were achieved through team coaching and having a relaxed classroom atmosphere that de-emphasized grades and encouraged risk-taking.
4. Diversity was achieved by having the faculty select teams of 'compatible opposites,' where the opposites were obtained from direct surveys (of the students' capabilities/knowledge, right-/left-brain thinking, motivation and ethnicity/gender) and compatibility exercises.

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REFERENCES

1. J. R. Katzenbach and D. K. Smith, *Wisdom of Teams*, Harvard Business School Press, Cambridge, MA (1992).
2. Boeing/IBM/General Motors executives, Engineering skills: what we'll need in 2010, Session 2307, panel discussion with industry, *2001 Annual ASEE Conference*, Albuquerque, NM, June 26, 2001.
3. Teams become commonplace in US companies, *Wall St. Journal*, November 28, 1995, p. 1.
4. ABET, *Engineering Criteria 2000*, The Engineering Accreditation Commission. Website: www.abet.org.
5. S. G. Adams, The effectiveness of the E-team approach to the invention and innovation, *J. Eng. Educ.*, **90**(4), October 2001, pp. 597–600.
6. Mary Besterfield-Sacre, *National Collegiate Inventors and Innovators Alliance (NCIIA) Course/Program Evaluation Survey*, Department of Industrial Engineering, University of Pittsburgh, October 2002. Contact: mbsacre@engr.pitt.edu
7. US General Accounting Office, *Best Practices, DOD Teaming Practices Not Achieving Potential Results*, Report to the Chairman and Ranking Member, Subcommittee on Readiness and Management Support, Committee on Armed Services, US Senate, GAO-01–510, April 2001.
8. P. Blowers, Group selection process—how to use a student skill self assessment to get balanced groups, *Proc. ASEE Pacific Southwest Section*, Spring 2002 Conference, California State University, Fresno, April 8–9, 2002.
9. G. M. Rogers and J. K. Sando, *Stepping Ahead: An Assessment Plan Development Guide*, Rose-Hulman Institute of Technology, NSF Grant EEC-9529401 (1996). Contact gloria.rogers@rose-hulman.edu.
10. M. Mendelson and R. Noorani, Improving undergraduate engineering education in the US and abroad using EC 2000, *Proc. Int. Conf. Engineering Education (ICEE)*, Taipei, Taiwan, August 13–16, 2000. Published in CD ROM, Contact: mmendels@lmu.edu.
11. M. I. Mendelson, Quality assessment in engineering management graduate program, *ASEE Conference Proceedings*, Seattle, WA, June 28–July 1, 1998, Session 2455: Measuring Graduate Program Quality. CD-ROM Publication.
12. National Collegiate Inventors and Innovators Alliance (NCIIA). See website: www.nciia.org.
13. Panel discussion, Effective teams for the 21st century, *5th Annual NCIIA Conference*, Washington, DC, March 6–9, 2001. See website: www.nciia.org.
14. C. D. Downing, Essential non-technical skills for teaming, *J. Eng. Educ.*, **90**(1), pp. 113–117, 2001.
15. *Random House Dictionary of the English Language*, 2nd Edition, unabridged, Random House Publisher, New York (1987).
16. D. Harrington-Mackin, *The Team Building Tool Kit: Tips, Tactics, and Rules for Effective Workplace Teams*, American Management Association, New York (1994).
17. Qualities of Creative People, *Wall St. Journal*, September 16, 1997, p. 1.
18. M. I. Mendelson, Entrepreneurship in a Graduate Engineering Program, *J. Eng. Educ.*, **90**(3), October 2001, pp. 601–607.
19. R. Dunn, D. P. Cavanaugh, B. M. Eberle, R. Zenhausern, Hemispheric Preference: The Newest Element of Learning Style, *The American Biology Teacher*, **44**(5), May 1982, pp. 292–294.
20. W. E. Deming, *The New Economics: For Industry, Government, Education*, 2nd edition, The MIT Press, Cambridge, MA (2000).
21. C. R. Rogers, *A Way of Being, The Founder of the Human Potential Movement Looks Back on a Distinguished Career*, Houghton Mifflin Company, New York, NY (1980).
22. F. S. Perls, Gestalt Therapy and Human Potentialities, *Explorations in Human Potentialities,* (Herbert A. Otto, ed.) Springfield, Illinois: Charles C. Thomas (1966).

23. Albert Ellis, The No Cop-Out Therapy, *Psychology Today*, July 1973, pp. 56–62.
24. William Glasser, Reality Therapy, A New Approach to Psychiatry, Harper & Row Publishers Inc., New York, NY (1965).
25. A. H. Maslow, *Motivation and Personality*, 3rd edition, Harper & Row Publishers Inc. (1987).
26. D. Goleman, *Emotional Intelligence*, Bantam Books, New York, NY 1995.
27. J. R. Fisslinger, *Aura Mastery*, Inneractive, Marina del Rey, CA, (1998). Internet: http://www.inneractive.com.
28. Steven J. Weiner, *The Language of Recovery from Co-dependency and Addiction*, self-published in 1991.
29. D. C. Montgomery, G. C. Runger and N. F. Hubele, *Engineering Statistics*, John Wiley & Sons, Inc., New York (2000).

APPENDIX

This appendix describes the type and characteristics of the teams that were evaluated at LMU. In addition it includes samples of the direct surveys and compatibility exercises used for team selection.

Team characteristics

The following table describes the profiles of the type of students in the teams that were studied. The teams of engineers and the business students were multidisciplinary. The primary functions of the engineers were concept generation, product design, proto-type implementation and communication with the business students. The primary functions of the business students were establishing the targeted market, marketing and communicating with both the targeted market and the engineers.

Table A1. Team profile

Type	Engineers, System Engineers, Team Leaders, Managers, Business and Technical Planners
Working Experience	Typically 4 to 10 years
Gender	Women: 25% to 33%, Men: 67% to 75%
Ethnicity	Asians, Afro-Americans, Hispanics and Caucasians
Age Range	25 to 35

Direct surveys: thought, behavior and motivation survey

NAME: _____

INSTRUCTIONS: Please circle either the left or right statements in each column based on the way that you predominately think and behave. Also, record your priority [1—4] for behavior and motivation in the relevant questions below. There are no 'right' or 'wrong' answers.

Thought: Do you . . . [circle]

1. Find different ways to look at things?	or	1. Find absolutes when judging issues?
2. Avoid looking for 'right' or 'wrong?'	or	2. Seek 'yes' or 'no' justification?
3. Become concerned with change?	or	3. Become concerned with stability?
4. Make illogical jumps from one step to another?	or	4. Make logical jumps from one step to another?
5. Welcome new information?	or	5. Selectively choose what to consider?
6. Progress by avoiding the obvious?	or	6. Progress by using established patterns?
7. Avoid guarantees?	or	7. Guarantee at least minimal standards?

Behavior:

8. How do you behave under stress? [Circle]	Talkative	Quiet
9. Under stress, how do you respond? [Circle]	Emotionally	Mechanically
10. Under stress, how do you best learn? [Circle]	Globally	Sequentially (step by step)
11. How do you handle unexpected events? [Circle]	Spontaneously	Predictably

12. Under stress, what do you communicate? [Give your priority below: 1 = highest, 4 = lowest]

Thoughts [ ] Behavior [ ] Feelings [ ] Energy [ ]

13. Under stress, how do you communicate? [Give your priority below: 1 = highest, 4 = lowest]

Assertively [ ] Passively [ ] Aggressively [ ] Passively/Aggressively [ ]

Motivation:

14. What motivates you? [Give your priority below: 1 = highest, 4 = lowest]

Creativity [ ] Team Collaboration [ ] Praise [ ] Course Grade [ ]

15. How do you solve problems? [Give your priority below: 1 = highest, 4 = lowest]

Collaboratively [ ] Emotionally [ ] Analytically [ ] Intuitively [ ]

Spatial nonverbal compatibility exercise

In order to determine spatial compatibility, the students performed a spatial exercise and their spatial boundaries were determined. The students were paired in duos, and arbitrarily one student was labeled as 'speaker' and the other was labeled as 'listener'. First, in silence, the speaker moved relative to the listener; then the roles of the speaker and listener were reversed. The close distance of the speaker was measured as the closest distance that the speaker could get to the listener before becoming significantly distracted. The far distance of the speaker was measured as the largest distance away from the listener that the speaker could be before becoming significantly distracted. The relaxed distance was measured as the distance from speaker to listener where the speaker felt most comfortable.

Table A2. Spatial boundaries

Name:	Date:
Spatial-Speaker	Boundaries
Aggressive Close Distance (inch)	
Assertive Relaxed Distance (inch)	
Passive Far Distance (inch)	

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