Differentiated Team Training in a Multidisciplinary Engineering Projects Course

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Abstract

The ability to function effectively in teams is an important contributor to career success in engineering. Unfortunately, specific training designed to improve team effectiveness is not often incorporated into engineering education. Even when such training is provided, the absence of clear comparisons makes it difficult to evaluate effectiveness. Providing two kinds of team training to two groups of students in an engineering projects course allows comparisons between different methods.

Utilizing this approach, two types of team training were offered to senior-level and graduate engineering students in an elective projects course at the University of Missouri – Rolla. The effects of conventional training in handling communication and team dynamics were compared with the effects of Action Science-based training in voicing inquiries and perspectives. Both quantitative and qualitative data were used to evaluate the two approaches to training.

Introduction

The ability to successfully work in teams is a crucial ingredient for success in the workplace [1]. Unfortunately it is often a neglected part of an engineer's education. The ability to function effectively in a team is even a requirement for accreditation, as stated in ABET's 2003-2004 General Criteria: *Engineering programs must demonstrate that their graduates have…an ability to function on multidisciplinary teams (I.3.d)*. However, while engineering students are generally given a great deal of direction and instruction in the technical aspects of their work, they are often thrown into teams without ample guidance to lead them through the complexities of team dynamics. These experiences often do not prepare students for the obstacles that multidisciplinary teams meet in industry, research and academia. Good team skills are not learned merely by placing students in teams [2].

The technical problems faced by engineering graduates are complex and often require collaborative effort. Engineers interact in the workplace with technical peers in other disciplines at all stages of design, development, and application. Hence, engineering work is increasingly oriented toward boundary-crossing, multi-disciplinary team activity. The potential and need to improve engineering training and education regarding team soft skills such as team dynamics and communication are widely recognized [3]. Current accreditation criteria address this need directly by requiring that engineering graduates demonstrate an ability to function on multidisciplinary teams [4]. And, efforts to enhance required senior design experiences often address the challenges of team communication and multi-disciplinary projects [5]. A major challenge of educating engineers is to balance development in meeting technical aspects of a project and in handling the process of teamwork. Planning, scheduling, organizing, etc. all become more difficult if multi-disciplinary work is required. Specialists frequently tend to limit their perception of technical problems and options to their own discipline. Awareness of the constraints, terminology, and needs of the other disciplines can be key in many situations. Research has shown that ineffective or insufficient training for the team environment can undermine team performance [6]. Also, research focusing on multi-disciplinary teams has identified communication and organizational problems as critical factors [7].

While there may be little disagreement that team skills education is a positive addition to engineering coursework, there have been few or no comparisons between different approaches to supplying that education. Research has generally focused on evaluating the effect of a particular team skill education program (e.g., [1], [8]).

To begin to address the need for comparative studies on approaches to engineering team skill education in multidisciplinary projects, an exploratory study was conducted in which two types of differentiated training were administered to a Senior-Graduate level multidisciplinary projects course at the University of Missouri at Rolla. The following sections describe the setting for the research, describe the two approaches to team skill education used, and provide an overview of the training and its results.

Setting

The senior-level/introductory-graduate course "Smart Materials and Sensors" (EE/ME/AE329 and CE 318) is a multidisciplinary course for electrical, mechanical, aerospace, and civil engineering majors and has co-listing pending for engineering management majors. It was developed as part of a prior National Science Foundation grant [9] and is typically offered once a year. The technical interest area is smart structures, which involves the intelligent monitoring, and control of structures using permanent sensors, actuators, and processors. It crosses traditional boundaries by combining materials, manufacturing, sensing, signal processing, structural analysis, etc. The learning objectives of this interdisciplinary course are:

(1) To integrate cross-disciplinary knowledge,
(2) To build interdisciplinary collaborative skills, and
(3) To gain related applied experience [10].

Instructional delivery is tailored to the desired learning objectives of the course and to the multidisciplinary mix of students through a structured combination of preliminary tutorials, Socratic lectures, group collaboration on progressively more involved projects, and active laboratory experiences including the UMR Smart Composite Bridge [11]. All assignments build on the content of the tutorials and lectures and grow more dependent on collaborative effort as the semester progresses. The last half of the semester is devoted to complex team projects.

Team collaboration is a central part of the course. Team membership of typically four students is multidisciplinary and is maintained throughout the semester in order to allow between-member dynamics to mature. The group activities are structured with each student having a distinct content specialty or interest and having specific assigned roles in accordance with cooperative learning theory [12]. In addition, individual grades to promote accountability and group grades to promote interdependence are combined as per components-of-cooperative learning theory [13]. Several exercises and discussions are typically included on the nature and group dynamics of engineering teams. These initial team homework and laboratory assignments give the students considerable experience with their teams and interdisciplinary interaction before the final projects. The final project is a Problem-based-Learning-type project in which a multifaceted, non-unique technical solution is required and student teams have the responsibility to identify resources and formulate strategies [14]. The project solutions are presented to the rest of the class to supplement the instructor-delivered lectures in the first half of the course. Hence, the solution and communication tasks are non-contrived in that they serve an educational function for the other teams.

Sixteen students participated in the class during the semester of this study. Each was a member of a four-person team. Table 1 describes the characteristics of these teams.

Team Number	1	2	3	4
Average GPA (on a 4 point scale)	3.575	3.125	3.800	3.500
Gender (1=100% male, 0=100% female)	0.75	1	0.5	0.75
Level (1=100% Grad, 0=100% Undergrad)	0.50	0.75	0.5	0.75

Table 1

To evaluate whether efforts at creating a collaborative environment were successful, a measure of group goal interdependence [15] was administered. The instrument measured dimensions of goal interdependence, including competition and cooperation. The students were asked to evaluate a “typical” class at the beginning of the semester and to evaluate the class under study at the end of the semester. The evaluations were made on a seven point Likert scale, with higher numbers indicating higher levels of the perceived measure. Measures of perceived competition and cooperation illustrate that, while all teams expressed reduced competition between students in the course, Team 4 alone expressed reduced cooperation when comparing this course to a typical course. Figures 1 and 2 present the results of these measures.

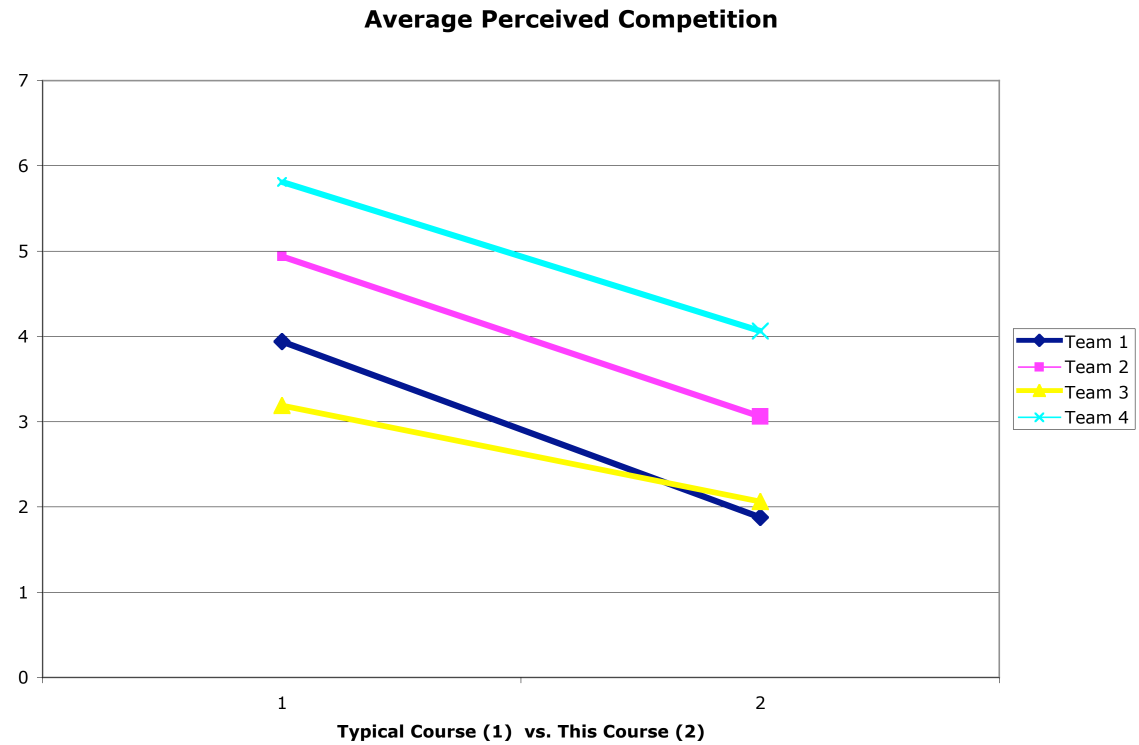

Figure 1

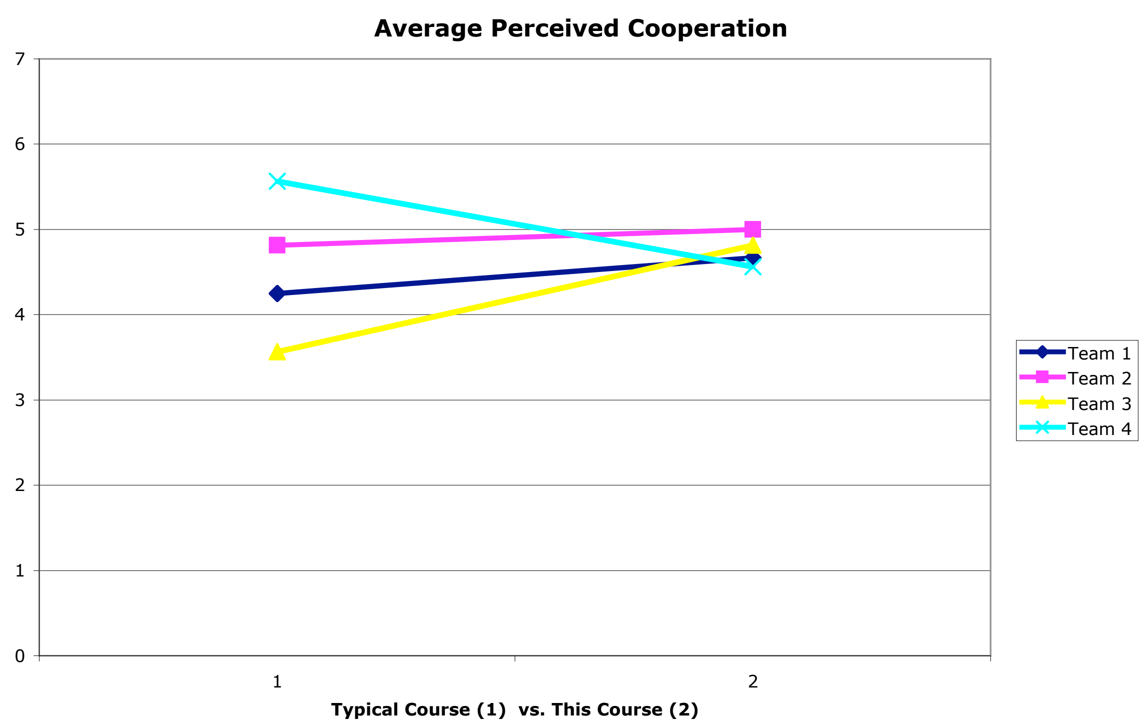

Figure 2

These results indicate that, with the possible exception of Team 4, the goal of increased collaboration was met.

Conventional versus Action Science education

Differentiated team skill education was provided to the four teams in the multidisciplinary projects course. Two types of training were provided: conventional training and training in "Action Science". Both the conventional and the Action Science modules were presented in four one-hour sessions. Two teams received the conventional education and two teams received the Action Science education. To limit concerns that the effects of the training might be influenced by the expertise of the presenter, all education modules were presented to the class by a graduate research assistant. The modules were presented in weeks 2, 4, 7, and 9 of a sixteen-week semester. This provided the students an opportunity to put the training to use during their team design project, which occupied weeks 12 through 16.

The conventional training provided team skill training covering topics such as those typically suggested [16] as essential for teams. The education consisted of six modules covering the following topics:

Practicing effective listening
Communicating across cultures
Understanding the difference between facts and inferences
Building Trust
Resolving conflict
Solving Problems

Each training session included an exercise to illustrate the lessons taught. For example, the module on building trust included an exercise where students were blindfolded and had to rely on a team member to help them negotiate through several halls. Homework drove home the lessons by asking for application to the students' team. The modules presented and approach taken was typical of most team skill training.

The Action Science training, however, took an entirely different approach to improving team skills. Action Science is an approach to participative inquiry that has its roots in organization development and the general field of "Action Research" [17]. Action Science is aimed at increasing the ability of engineering teams to critically reflect and inquire into their own social and scientific practice, so that they can work together more effectively and complete innovative, quality projects. It has been shown to improve the extent to which important information is shared among team members [18]. One of the greatest distinctions between conventional team training and Action Science training is that, while conventional training emphasizes the description of how things are, Action Science emphasizes understanding how things might be changed. Thus, for example, while conventional training might focus on how to appropriately evaluate team members at the completion of a project, Action Science might seek to understand what prevents evaluation from occurring during the course of the project, and how that might be changed.

Another important distinction is the degree to which Action Science emphasizes attention to the specifics of team interaction rather than the more global abstractions that are the focus of conventional team training. So, for example, while conventional training might advocate giving feedback as a way to improve performance, Action Science would be concerned with what, specifically, was said during the process of giving feedback and what the recipient thought and said in response.

The Action Science training was divided into 10 modules along the lines of Rossmoore's [19] approach to building these skills. The modules covered the following topics:

What is Directly Observable Data
Advocating your positions
Illustrating your viewpoints clearly
Advocating Predictions and Recommendations (giving advice)
Effective Inquiry
Systems causality – the dynamics of team influence
Climbing ladder of inference – different conclusions from the same data
Moving your theories from the private to the public sphere
Openness and Confrontability
Expressing Demands and Preferences

More information on the Action Science approach can be found in Argyris' work [20]. As with the conventional team training, homework was assigned with the purpose of helping the students apply the training to their own team experience.

Description of the results

Several types of data were collected to evaluate the two forms of education. Three types will be discussed here; the quantitative results of team exercises, data from an analysis of team conversations during these exercises, and an end-of-semester survey.

As part of the evaluation of the team skill education, the student teams completed pre- and post-training team problem-solving exercises. In order to capture the teams' conversations accurately, the exercises were performed in an internet chat-space. The pre-training exercise was a commercially available exercise that involved balancing a budget. The quantitative measure of performance on this exercise was the amount of profit generated by the new budget. The post-training exercise is one that is currently under development by the authors. It had an engineering design focus based on creating new designs for UMR's Solar Car. The quantitative measure of performance on this exercise was the number of miles that the car would be able to travel.

The outcomes of the pre-and post-training are illustrated in Table 1. There are no clear distinctions between the conventional and Action Science groups.

	Conventional Teams		Action Science Teams	
Team Number	1	2	3	4
Pre-test results (Amount of Profit)	[-$24,940]	[-$55,000]	$30,007	[-$14,993]
Post-test results (Miles traveled)	NA	359	360	354

Table 1

Since Action Science has the goal of helping individuals share information more effectively, it is expected that an analysis of the team conversations along these lines might reveal differences between the training groups. The exercises both contained certain kinds of information that were critical to the team's ability to complete the exercise. This information had to do with the individual goals that each team member had. In the exercises each individual had three goals, ranging from the most important (Level 1) to the least (Level 3). The extent of information sharing about individual goals was measured in the team conversations. Table 2 shows that information sharing increased appreciably with Action Science education.

	Conventional Teams		Action Science Teams	
Team Number	1	2	3	4
Pre-test results (Goals shared)	0	1	3	1
Post-test results (Goals shared)	0	5	9	6

Table 2

Action Science is expected to have an effect on the ability of team members to change their behavior and/or perspectives on others' behavior. A post-course survey provided some indication that the Action Science team skill education was more effective than the conventional education. Table 3 contains survey results from the nine people that responded.

Question – Did the education modules…	Action Science –Percent Improved	Conventional –Percent Improved
Help your team become more effective?	50%	20%
Help change the behavior of your team-mates?	25%	20%
Help change your own behavior?	50%	40%
Help change your evaluations or judgments of others	75%	0%

Table 3

Finally, as an additional evaluation, perceived levels of Constructive Controversy [15] were measured. This instrument provides a measure of how well team members are able to understand opposing positions and integrate diverse ideas. The results of this measure are reported in Figure 3.

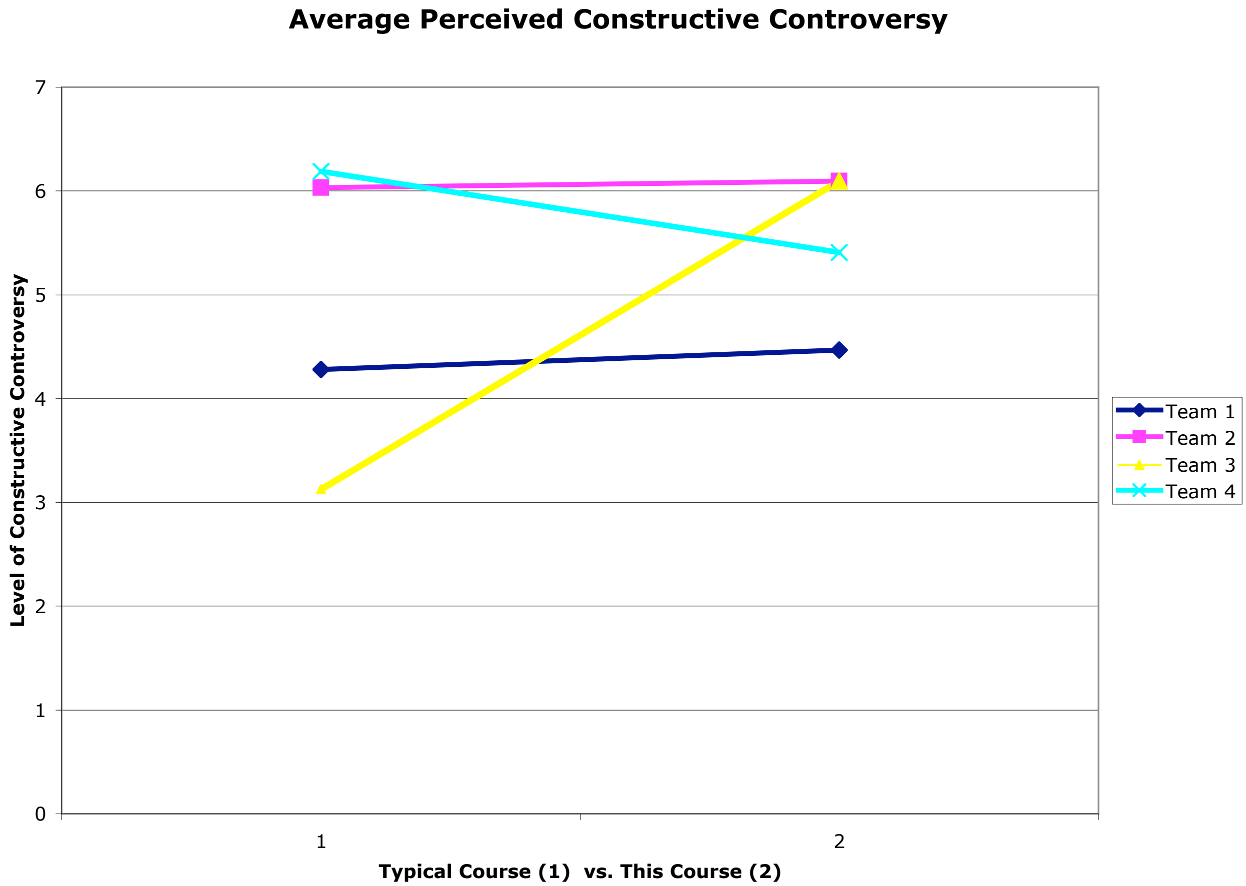

Figure 3

While the two conventionally trained teams reported nearly the same level of constructive controversy in this course as in a typical course, there were anomalous results in the Action Science teams. Team 3 reported a large average increase in Constructive Controversy, while Team 4 reported a slight decrease.

Conclusions

This paper described a preliminary project to compare two different types of team skill education, conventional and Action Science. While results concerning performance outcomes are indefinite, other results appear to show that Action Science training produces better results than conventional training. Teams given Action Science training appear to share information more effectively and be better able to change their behavior and perceptions.

While the results from Action Science Training appear to be positive, there are some curious results, mostly having to do with Team 4. This team reported reduced levels of average perceived cooperation as well as reduced levels of constructive controversy when compared to a typical course. While the results of this study are not significantly significant, these results bear further exploration. One potential explanation is that, while Action Science training is designed to help people raise and explore issues, in some cases this may result in issues being raised which the involved individuals are not yet able to handle constructively. The relatively brief training may help individuals address simple problems effectively, but may aggravate more complex problems as individuals raise them without the level of skill needed to resolve them. More extended training may be needed to resolve more difficult issues effectively.

Overall, these results are intriguing enough to deserve further investigation. It is the intent of the researchers to pursue studies with larger sample sizes in order to seek statistically valid results.

1. Bahner, B., 1996, "Report: Curricula Need Product Realization," *ASME-NEWS*, vol. 15, no. 10, American Society of Mechanical Engineers, 1996, pp. 1-6.
2. Seat, Elaine and Susan M. Lord, "Enabling Effective Engineering Teams : a program for teaching interaction skills", *Journal of Engineering Education,* Oct. 1999, p. 385-390.
3. Hissey, T. W. "Education and Careers 2000: Enhanced Skills for Engineers," *Proceedings of the IEEE*, **88**(8), 1367-1370, (2000).
4. Engineering Accreditation Commission, "Engineering Criteria 2000," *2000-2001 Criteria for Accrediting Engineering Programs*, (Accreditation Board for Engineering and Technology, New York, NY, 1999), pg. 32.
5. McDonald, David James Devaprasad, Paul Duesing, Ajay Mahajan, Mohamad Qatu, Maurice Walworth, "Re-Engineering the Senior Design Experience with Industry-Sponsored Multidisciplinary Team Projects," *Proceedings of the ASEE/IEEE Frontiers in Education '96*, 1996
6. Loehr Linda, "Between Silence and Voice: Communicating in Cross-Functional Project Teams," *IEEE Trans. Prof. Commun*., vol. 34, no. 1, pp. 51-56, 1991.
7. Fornaro Robert J., Margaret R. Heil, and Steven W. Peretti, "Enhancing Technical Communication Skills of Engineering Students: An Experiment in Multidisciplinary Design," *Proceedings of the ASEE/IEEE Frontiers in Education '01*, 2001.
8. Bhavnani, Sushil H. and M. Dayne Aldridge, "Teamwork across Disciplinary Borders: A bridge between College and the Work Place", *Journal of Engineering Education*, January 2000, pp 13 – 16.
9. Watkins, S. E. and Hall, R. H., "Smart Materials and Sensors" *Smart Engineering*, University of Missouri-Rolla, (2001), Available WWW: http://campus.umr.edu/smarteng.
10. Watkins, S. E., R. Hall, H. Chandrashekhara, K. and Baker, J. M. "Interdisciplinary Learning, through a Connected Classroom," Accepted by *International J. of Engineering Education*
11. Watkins, S. E. Unser, J. F. Nanni, Chandrashekhara, A. K. and Belarbi, A. "Instrumentation and Manufacture of a Smart Composite Bridge for Short-Span Applications," *Smart Structures and Materials 2001: Smart Systems for Bridges, Structures, and Highways*, Proc. SPIE **4330**, 147-157, 2001, 4-8 March 2001, Newport Beach, CA.
12. Dansereau, D. F. "Cooperative Learning Strategies," In *Learning and Study Strategies: Issues in assessment, Instruction, and Evaluation*, C. E. Weinstein, E. T. Goetz, and P. A. Alexander, eds., (Academic Press, Orlando, FL, 1988), 103-120.
13. Johnson D. W. and Johnson R. T.*, Learning Together and Alone: Cooperative, Competitive and Individualistic Learning*, 4th ed., (Allyn and Bacon, Boston, MA, 1994).
14. Watkins, S. E. and R. H. Hall, "Complex Problem-Solving using Structured Collaboration," *Innovation 2003: World Innovations in Engineering Education and Research* , edited by W. Aung, M. H. W. Hoffmann, N. W. Jern, R. W. King, L. M. S. Ruiz, (iNEER, Arlington, VA, 2003).
15. Alper, S., Tjosvold, D., and Law, K. S. "Interdependence and controversy in group decision making:

Antecedents to effective self-managing teams", *Organizational Behavior and Human Decision Processes*, vol. 74, 1998, pp. 33-52
16. Downing, Craig G. "Essential Non-Technical Skills for Teaming", Journal of Engineering Education, January 2001, pp 113-117.
17. Reason, Peter and Hilary Bradbury (Eds.), *Handbook of Action Research: Participative Inquiry and Practice,* 2001, Sage, Thousand Oaks CA.
18. Luechtefeld, R. A. *Model II Behavior And Team Performance: An Experimental Design And Intertextual Analysis*. Unpublished doctoral dissertation, Carroll Graduate School of Management. Boston College, 2002.
19. Rossmoore, D. F.. *An Empirical Investigation of the Argyris and Schon Theory of Action Perspective*. Unpublished doctoral dissertation, University of California Graduate School of Management.1984.
20. Argyris, C., Putnam, R., & McLain Smith, D.. *Action Science*. San Francisco: Jossey Bass. 1990.

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