AC 2010-400: AN ANALYSIS OF LITERATURE OF THE DEVELOPMENT OF LEADERSHIP SKILLS IN ENGINEERING AND RELATED DOCTORAL PROGRAMS

Joy Watson, University of South Carolina

Jed Lyons, University of South Carolina

An Analysis of Literature of the Development of Leadership Skills in Engineering and Related Doctoral Programs

Abstract

It has been stated that engineering Ph.D. graduates do not have the leadership skills needed to organize, manage and establish effective research groups or to appreciate the applied problems, knowledge and culture of other fields[1]. The objective of this study is to investigate and document the instructional strategies to both develop and assess leadership skills of engineering doctoral students. A literature review was conducted that examined approximately forty papers on this subject. This paper presents a critical analysis of the literature on this subject, and suggests directions for future research.

Introduction

The objective of this paper is to investigate the instructional strategies for developing and assessing leadership skills of engineering doctoral students. Within six years of obtaining a Ph.D., 80% of graduates will not hold tenure track positions in academia. Many of these graduates take positions in the for-profit business sector (industry) according to NSF Science and Engineering Indicators[2]. Currently, industry states that Ph.D.s do not have the leadership skills to organize, manage and establish effective teams of researchers that outperform their competition while appreciating the applied problems, knowledge and culture of other fields[1, 3]. Leadership skills, like many other skills, are gained through training and mentoring[4]. Several different instructional strategies have been developed to integrate the technical knowledge and leadership skills that industry desires in its Ph.D.s. This paper is a critical analysis of various instructional strategies and will address the following questions:

- How are leadership skills defined?
- What are the different instructional strategies for developing leadership and what are their strengths and weaknesses?
- How are leadership skills measured or assessed?
- What direction should be pursued in future research?

Methodology

A literature search and review was performed to address the research questions. The literature search was conducted using Web of Science, ERIC and Business Source Premier databases. Numerous search strings were entered to find relevant papers. For instance, the search string:

> TS=((scien* or chemi* or physics or engineer* or math* or industr*) and (grad* or graduate or master or doctoral or phd or ph.d. or doctor*) and (leadership) and (teach* or learn* or skill*))

was used in a Web of Science search that provided the authors with 140 relevant papers. A large collection of papers was examined in order to develop working definitions of leadership skills. These definitions were derived primarily from a series of articles discussing industrial employers' desired knowledge, assets and skills of employees, e.g. Sekhon[5] and Sodhi[6]. After leadership was defined, additional literature was reviewed to determine current instructional and assessment strategies for developing leadership skills among engineering students, particularly engineering graduate students.

Definition of Leadership

The definition of engineering leadership is changing with the increased difficultly and complexity of today's problems[7]. Through this literature review, three interrelated leadership themes defining the skills and characteristic of effective leadership emerged: interpersonal leadership, visionary leadership, and lifelong learning leadership. Leaders must have interpersonal leadership skills because they work with others in a team setting. Visionary leadership skills are needed to create a change in the status quo. Lifelong learning leadership skills are needed to enable leaders and team members the ability to change direction with the market. Without these skills and characteristics a leader is merely a figurehead and often unsuccessful[3].

Interpersonal leadership skills include team building, motivating others and creating a professionally stimulating workplace. A leader needs the skills to build a strong, cohesive, and successful team by being able to resolve conflicts and incorporate the professional interests of team members into projects[7-12]. Motivating skills of leaders include the incorporation of team members' professional interests, developing team members' leadership skills and giving team members a stake in the problem[7, 9-11, 13-15]. A professionally stimulating workplace can be developed by the leader through brainstorming and modeling creative problem solving[7, 9, 15]. Studies have shown that a leader who possesses these interpersonal leadership skills has more successful projects than leaders without these skills[3].

A leader creates a vision, or change in the status quo. Depth and breadth of knowledge, along with problem solving skills, allow a leader to determine where a change is needed and communicate it to team members and other stakeholders. The leader and his or her team formulate a strategic plan to implement a vision, create metrics and enable the team to self-assess their progress[1, 7, 8, 11, 15-17]. During the implementation a leader deals with technological, economic, political and regulatory risks. He or she needs self-confidence and self-efficacy gained through a depth and breadth of knowledge in addition to past experiences[7].

Leadership requires lifelong learning because the implementation of a vision often requires knowledge or skills that the team, including the leader, may not possess[7, 13, 18]. The leader's job is to identify the skills that are lacking and find a way to acquire them. In academia a researcher needs to generate proposals for research; in industry a researcher needs to generate a business plan for product development. When a person possesses lifelong learning skills he or she is able to gain the knowledge and skills to generate the proposals or a business plan. In an environment where life-long learning is valued, individual team members develop a breadth and depth of knowledge and grow in their leadership skills, also adding to a professionally stimulating work environment[13, 19].

The three themes of leadership skills discussed above are not all inclusive. Project management skills, such as managing material resources and delegating tasks, often appeared in the literature[7, 8]. Project management skills are important for leading teams effectively. However, they can be acquired through degree and certificate programs[16, 20]. Lifelong learning leadership skills allow for the growth and development of additional skills as the market requires. If interpersonal, visionary and lifelong learning leadership skills are fully developed, it is a fair assessment that project management skills can be learned and retained by leaders.

Instructional Strategies to Develop Leadership Skills

Throughout the world many different programs exist to develop the leadership skills of students enrolled in engineering doctoral programs. Three different instructional strategies that enhance students' leadership skills and technical knowledge are: 1) academic research training, 2) academic and industry partnerships in research, and 3) learner centered courses. Other instructional strategies, such as degree or certificate programs in leadership do exist, but they do not show evidence of strengthening students' technical knowledge. This paper focuses on programs whose goal is both to educate doctoral students with technical knowledge and enhance their leadership abilities.

Academic Research Training Programs. Engineering doctoral education in the United States is based largely on an apprenticeship model. The degree includes of technical courses, a research based dissertation, and comprehensive exams. Students are assigned or choose a supervisor who is an acknowledged expert in the field of research[21, 22]. The supervisor guides each student individually through their research with various levels of support and indicates when a student is ready to publically defend his or her thesis[21]. Because of the nature of individualized instruction, some supervisors attempt to develop their students' leadership skills while others may not. However, it is hard to judge if this instructional strategy is effective in developing students' leadership skills because it is not well addressed in literature.

Industry and Academic Partnerships. Leadership skills can be taught through industry and academic partnerships where students perform their doctoral research in industry with guidance from an industrial and academic supervisor[23]. Such programs exist in the United States, Sweden, Denmark and the United Kingdom (U.K.)[21, 23-28]. More literature is available on the programs in the U.K., thus is the focus of this section. Universities in the U.K. have been partnering with industry for approximately twenty years with support from U.K.'s Engineering and Physical Sciences Research Council (the U.K.'s equivalent to the National Science Foundation). In addition to technical coursework, students take courses in strategic management, finance and human resource management. Students completing the program earn a research based engineering doctorate [25].

Students in the United Kingdom's program transition through four roles: consultant, researcher, innovator and entrepreneur. Initially a student is a consultant and determines the vision of the company through a series of audits. He or she will then transition to the role of researcher, which is similar to a traditional Ph.D. student. After a student's research is complete, he or she takes on an innovator role where the information learned as an auditor and researcher is developed and optimized. Finally, the student takes the entrepreneur role where he or she builds a business case to establish a new technology. Thus students take an idea from conception to market.

Throughout the four roles, students are developing their leadership skills. Visionary leadership skills, specifically communication skills, were developed through the series of audits. Students performed a gap analysis which allowed them to find the problem or potential for new product development, create a strategic plan and metrics which addressed their visionary leadership skills. Lifelong learning is emphasized by the students working in a fluid marketplace and the continual analysis and readjustment of the viability of the project. Visionary and lifelong leadership skills are addressed in industry and academic partnerships literature and show promise of developing more skilled leaders, but there is no indication that leadership skills are directly assessed.

The literature on industry and academic partnerships that addresses leadership skills are case studies that do not discuss developing leadership skills are team building, motivating others, creating a professional stimulating workplace, risk taking, identifying the skills needed by others and helping others acquire those skills. These leadership skills may or may not be developed in students completing academic and industrial partnerships, however the degree of development is difficult to determine because the assessment of the skills is not well-addressed in literature. One could speculate that since students are working in industry they are learning the leadership skills not discussed through observing leaders within the organization. Future studies are needed to address the leadership skill development of students through industrial and academic partnerships.

The studies of industrial and academic partnerships clearly explain the program in the specific case studies and discuss the unique challenges to their partnerships. On the other hand, the literature fails to discuss if the case studies are unique or representative of common practice throughout various partnerships making it difficult to determine if the case studies can be generalized. Doctoral research in industry has major obstacles it must overcome in order to become viable in the United States including: intellectual property, duration of the research project, funding for the project and graduate students' tuition and fees[24]. Industry and academic partnership show promise of developing students' leadership skills, but first an assessment of students' leadership skills must be addressed. If the partnerships do develop strong leaders, dissemination of the best practices of overcoming obstacles such as intellectual property, duration of the research project and funding must be developed before the partnerships can become prevalent instructional strategies in the U.S.

Learner Centered Courses. Leadership can be taught through learner centered courses where a major component of the course is a team project, and students have the flexibility to focus the project in an area of team interest. This instructional strategy has been used at Yale, University of California-Berkeley, and Rensselaer Polytechnic Institute in their engineering design, new product development and web design courses[10, 29-32]. Within the learner centered courses, two different, but complementary, instructional strategies emerge: 1) new product development and 2) self-assessment of a team project. These two instructional strategies develop leadership skills through a group project in a similar manner. However, there are differences on how visionary leadership skills are addressed as discussed below.

The new product development course was designed for graduate students at the University of California-Berkley in response to criticisms that academia is not teaching "flat world" or leadership skills[10]. Articles on a new product development course at University of California-Berkley discuss the experiences of students in the engineering, industrial design and business programs in two different studies. Students initially propose a project based on a problem or annoyance that students have observed. They perform market research and modify their project as needed, followed by concept prototyping and the financial analysis of the product. Students complete the semester by presenting their project to a professional panel of designers[10, 31].

Through the process of new product development, it is suggested that students increased their interpersonal, visionary and lifelong learning leadership skills. The new product development project devoted some time to team dynamics and team building, which could contribute to an increase their interpersonal leadership skills [31]. Students developed their visionary leadership skills when they found a problem and created a plan to solve their problem develop their product. The students with the more successful projects had a higher tolerance for ambiguity or risks[13]. Lifelong learning skills were developed when students had to determine what they knew and needed to know about the market for their product and then teach themselves the skills or knowledge needed to complete the project [32].

One of the articles discussed students' perceptions of the lessons learned through the course [32]. The second study was a series of case studies of new product development projects that began in the new product development course and extended into the marketplace upon completion of the course [13]. Both articles presented valid and reliable data. However, they did not discuss if students learned the leadership skills such as motivating others, self-assessing, and determining if others needed skills or knowledge to complete the project. The issue of students' mastery of leadership skills was also not addressed in literature. The two studies indicate that leadership skills could be developed through new product development courses but do not directly assess the leadership skills learned through participation in the course.

The self-assessed team project at Rensselaer Polytechnic Institute is a graduate level computer science class, with students working towards their Master's of Computer Science [30, 33]. In the class, students wrote a proposal on how they were going to develop a medium-sized web application in a self-formed group. They chose the domain, delivered functionality of a project site architecture, selected site usage routes, component details, and platform details for their web design along with determining their own grade specifications for the project. This proposal goes through multiple iterations to allow the instructor to address any ambiguities in student's grading specifications and other areas of the project. Both articles discuss students self-grading at the completion of the project [30, 32].

Students were taught leadership skills in the self-assessed team project in a similar manner to those in the new product development course, with more extensive work in visionary leadership skills. Visionary leadership skills were taught when teams determined their domain and functionality of their web-site and further developed as students develop performance measures for grading the project [30, 32]. The development of performance measures also enhanced their communication skills through the iterative process and allowed the instructor to assess student's visionary leadership skills. The students then critique themselves on their team's performance measures at the end of the project. A survey asking students about their comfort level in self-assessment at the beginning and end of the project showed an increased comfort level in self-assessment through use of this technique [30].

The motivation behind these studies on self-assessment projects is to allow students more flexibility and autonomy in their learning process or developing lifelong leadership skills through the self-assessment project. The development of interpersonal leadership skills is hard to judge because it is not addressed in literature. Both studies present valid and reliable data, but neither one discusses the assessment of interpersonal or lifelong learning leadership skills. The self-formed teams suggest that students develop less interpersonal leadership skills since they are likely to regroup into teams with proven track records where interpersonal leadership skills is less of a challenge. Perhaps if the groups were not self-selected, the interpersonal leadership skill might be further developed. It is difficult to determine the effectiveness of the project in developing lifelong leadership skills in students because a ambitious team may have challenged themselves in learning a new domain while another more lazy team could have used a very familiar domain. The two studies show that visionary leadership skills can be developed and suggest that interpersonal and lifelong leadership skills can be developed through self-assessed team projects, but further studies are needed to determine if self-assessed team projects develop interpersonal and lifelong leadership skills.

The three instructional strategies (academic research training programs, industry and academic partnerships, and learner centered courses) discussed fail to directly assess students' leadership skills. In the various instructional strategies for teaching leadership skills, the academic research training is not well-addressed in literature, thus no conclusion on the effectiveness of the instructional strategy can be determined without further research. The industry and academic partnerships appear promising in developing leadership skills, but students' leadership skills upon completing the partnership have not been assessed. The new product development course and self-assessed team projects indicate potential development of leadership skills, but again literature fails to discuss assessment of the students' leadership skills. The self-assessed team projects assess visionary leadership skills, but it does not discuss assessment of interpersonal or lifelong learning leadership skills. While all three instructional strategies show potential for developing leadership skills, only a few articles have been published directly assessing students' leadership skills. Thus direct assessments of students' leadership skills are needed in order to adequately determine the strengths and weaknesses of the various instructional strategies when teaching leadership so that they can be applied in preparing doctoral students for a career in industry.

Assessing Leadership Skills

In industry, managers often assess interpersonal leadership skills of others by a project's success. Employees with successful projects and more innovative performance tend to possess well developed interpersonal leadership skills [33]. This idea could translate into the classroom in team projects with the interpersonal leadership skills assessed indirectly through product performance. This assessment is not adequate, since teamwork is the students' interactions, not the resultant product. Behavioral observation is one method that directly assesses teamwork and interpersonal leadership skills. However, this method is time consuming and costly [34].

The Servant Organizational Leadership Assessment (SOLA) specifically addresses all of the elements of interpersonal leadership [35]. The SOLA is a survey administered to team members. It was developed through a field panel of fourteen leadership experts, then field tested with 828 people in 41 organizations throughout the U.S. and one in the Netherlands to insure validity.

The instrument's reliability was 0.98 using the Cronbach-alpha. Participants in the study included employees of secular and non-secular nonprofit organizations, for-profit organizations and public agencies. The participants ranged from positions of upper management to the workforce [35]. The SOLA does not specifically address assessment in university classroom settings or in an engineering research environment though it has been used to address leadership skills in industrial manufacturing [36]. Perhaps with modification SOLA could provide invaluable assessments to students, instructors and industry researchers on strengths and weaknesses of their interpersonal leadership skills.

Visionary leadership skills involve creating a metric to enable the team to self-assess their progress for creating change and reaching a goal. Students in the self-assessed team project previously discussed were directly assessed on their visionary leadership skills. The instructor assessed their performance measures through the various iterations of a group's proposal. The self-assessment method appears promising, especially to instructors who want increased personal satisfaction in teaching. This study took place in a computer science course with more mature students (average age was 33). Further studies are needed to determine if this instructional and assessment strategy is generalizable to other courses and less mature students.

Engineering is a field that is constantly changing. Lifelong (or self-directed) learning is an essential skill that research engineers need to be successful and for their industries to remain profitable. The Self –Directed Learning Readiness Scale (SDLRS) is a Likert Scale self-reporting questionnaire that assesses people's readiness to engage in self-directed learning. The SDLRS was developed in the late 1970s, and has been shown to have a reliability estimate of 0.87 using Cronbach-alpha and was substantiated in later studies [37]. The validity of this method has come under question by Field, but has been refuted and used in over 200 studies [38-40]. This method was used in a study involving engineering graduate students in order to assess their lifelong learning skills after writing an evaluation of a technical paper, but no results were discussed in the article and additional literature on the study was unavailable [38]. This assessment method appears to be valid and reliable to assess the life-long learning skills of individual students. However, it fails to address all of the elements of lifelong leadership skills, particularly determining the knowledge and skills that others within an organization need and creating an organizational climate that enables and encourages others to learn.

Future Areas of Research

Stronger leaders are needed in engineering research, both in industry and academia[1]. Unlike industrial research that tends to focus on applied research and development due to constraints of quarterly earnings, academic engineering research is able to conduct long-term basic research[41, 42]. Traditionally students have been trained in academic research, but less than 20% of the Ph.D.s remain in academic research positions within six years of obtaining their doctorate [43]. Industry claims that the academically trained Ph.D.s do not possess the leadership skills required in establishing effective research groups and approaching interdisciplinary applied problem solving[1]. Industry feels that it is the responsibility of the academic community to educate students so that upon graduation they are better prepared for their job responsibilities in industry.

Academia recognizes the need to change, but raises the concern that teaching leadership skills will detract from the quality of students' research[1]. While continuing the more traditional academic research training, academia has created alternative instructional strategies comprising academic and industry partnerships and learner centered courses. Neither the traditional nor the alternative instructional strategies were adequately assessed with regard to developing students' leadership skills. With the current economic crisis facing universities today, the fundamental question of the effectiveness of instructional strategies promoting leadership must be answered in order to efficiently prepare engineering doctoral students for the future.

Several assessment methods have been developed to measure some of the elements of leadership, but may need modification in order to address leadership development in doctoral education. The SOLA addresses all of the elements of interpersonal leadership skills, but it does not address assessment in the university classroom or in an engineering research environment [35]. The self-assessed team project assesses the elements of visionary leadership with "older" graduate students [31]. This method appears to be effective at assessing visionary leadership skills, but further studies are needed to determine if it is applicable in other graduate engineering disciplines and with younger students. Elements of lifelong learning leadership skills can be directly assessed by the SDLRS, though it fails in assessing the leadership elements of others' knowledge and skill gaps and creating an organizational climate that encourages others to learn [37]. So in order to answer the basic question of the instructional strategies' effectiveness, the effectiveness of developing students' leadership skills must be assessed to answer the basic question of how it can be taught in a doctoral setting.

Acknowledgement
This material is based upon work supported by the National Science Foundation's Innovations in Engineering Education, Curriculum, and Infrastructure program, under Grant No. 0935039. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

Bibliography

1. Akay, A., A Renaissnce In Engineering PhD Education. *European Journal Of Engineering Education* 2008, *33* (4), 403-413.
2. National Science Board Science and Engineering Indicators. National Science Foundation: 2008; Vol. 1.
3. Hogan, R.; Hogan, J., Assessing Leadership: A View From The Dark Side. *International Journal Of Selection And Assessment* 2001, *9* (1/2), 40-51.
4. Hunt, C., Careers In Chemistry: Keys To Success...Beyond Hard Work! *American Chemical Society Graduate Education Newsletter* 2007, *6* (1), 1-3.
5. Sekhon, J. G., The PhD Education of Industrial Mathematicians in Australia. *Bulletin Of The Australian Mathematical Society* 1985, *32* (3), 477-479.
6. Sodhi, M. S.; Son, B. G., ASP, The Art And Science Of Practice: Skills Employers Want from Operations Research Graduates. *Interfaces* 2008, *38* (2), 140-146.
7. Thamhain, H., Leading Technology-Based Project Teams. *Engineering Management Journal* 2004, *16* (2), 35-42.
8. Burke, C. S.; Stagl, K. C.; Klein, C.; Goodwin, G. F.; Salas, E.; Halpin, S. M., What Type of Leadership Behaviors Are Functional in Teams? A Meta-Analysis. *Leadership Quarterly* 2006, *17* (3), 288-307.
9. Oh, K.; Kim, Y.; Lee, J., An Empirical Study of Communication Patterns, Leadership Styles, and Subordinate Satisfaction In R&D Project Teams In Korea. *Journal Of Engineering And Technology Management* 1991, *8*, 15-35.

10. Cobb, C. L.; Agogino, A. M.; Beckman, S. L.; Speer, L., Enabling and Characterizing Twenty-First Century Skills in New Product Development Teams. *International Journal of Engineering Education* 2008, *24* (2), 420-433.
11. Dennis, R.; Bocarnea, M., Development Of The Servant Leadership Assessment Instrument. *Leadership And Organization* 2005, *26* (8), 600-615.
12. Pittinsky, T. L.; Simon, S., Intergroup Leadership. *Leadership Quarterly* 2007, *18* (6), 586-605.
13. Gardner, W. L.; Avolio, B. J.; Luthans, F.; May, D. R.; Walumbwa, F. In *"Can You See The Real Me?" A Self-Based Model of Authentic Leader And Follower Development*, 2005; Pp 343-372.
14. Corson, B., Leadership by Design And Design by Collaboration: Processes for Illuminating 'The Box'. *International Journal Of Engineering Education* 2003, *19* (1), 41-52.
15. Basadur, M., Leading Others to Think Innovatively Together: Creative Leadership. *Leadership Quarterly* 2004, *15* (1), 103-121.
16. Jablokow, K. W., Developing Problem Solving Leadership: A Cognitive Approach. *International Journal of Engineering Education* 2008, *24* (5), 936-954.
17. Zaccaro, S.; Banks, D., Leader Visioning And Adaptability: Bridiging the Gap Bewteen Research and Practice on Developing The Ability to Manage Change. *Human Resources Management* 2004, *43* (4), 367-380.
18. Shuman, L. J.; Besterfield-Sacre, M.; Mcgourty, J., The ABET "Professional Skills" - Can They Be Taught? Can They Be Assessed? *Journal Of Engineering Education* 2005, *94* (1), 41-55.
19. Avolio, B.; Gardner, W., Authentic Leadership Development: Getting to The Root of Positive Forms of Leadership. *The Leadership Quarterly* 2005, *16*, 315-338.
20. Seymour, S. J.; Kossiakoff, A., The Technical Management and Systems Engineering Programs. *Johns Hopkins Apl Technical Digest* 2005, *26* (3), 243-247.
21. Kolmos, A.; Kofoed, L. B.; Du, X. Y., Phd Students' Work Conditions and Study Enviornment in University- and Industry-Based PhD Programmes. *European Journal Of Engineering Education* 2008, *33* (5-6), 539-550.
22. Lange, K.; Baillie, C., Exploring Graduate Student Learning in Applied Science and Student-Supervisor Relationships: Views of Supervisors and Their Students. *Engineering Education* 2008, *3* (1), 30-43.
23. Salminen-Karlsson, M.; Wallgren, L., The Interaction of Academic and Industrial Supervisors in Graduate Education-An Investigation of Industrial Research Schools. *Higher Education* 2008, *56*, 77-93.
24. Seay, J.; Eden, M., Challenges of Implementing a Joint Industrial-Academic Research Project as part of a Nontraditional Ph.D. Dissertation. *Chemical Engineering Education* 2008, *42* (2), 112-116.
25. Kerr, C.; Ivey, P., The Engineering Doctorate Model of Consultant/Researcher/Innovator/Entrepreneur for New Product Development-A Gas Turbine Instrumentation Case Study. *Technovation* 2003, *23*, 95-102.
26. Leonard, R.; Barber, K., Postgraduate Training & Research in Collaboration with Industry (Twenty Years of Experience in The U.K.). In *International Conference On Engineering Education*, Rio De Janeiro, Brazil, 1998;
27. EngD: Engineering Tomorrow. *EPSRC Newsline* 2002/2003, *Winter*;
28. Llewellyn, D., EngD Degree at Serc-Parnaby-Doctorate-Center (Wales). *Ironmaking & Steelmaking* 1994, *21* (1), 10-12.
29.. Apfel, R. E.; Jeremijenko, N., Synthesis: Integrating Real World Product Design and Business Development with the Challenges of Innovative Instruction. *International Journal Of Engineering Education* 2001, *17* (4-5), 375-380.
30. Ellis, H., An Assessment of a Self Directed Learning Approach in a Graduate Web Application Design and Development Course. *IEEE Transactions On Education* 2007, *50* (1), 55-60.
31. Hey, J.; Van Pelt, A.; Agogino, A.; Beckman, S., Self-Reflection: Lessons Learned in a New Prduct Development Class. *Journal Of Mechanical Design* 2007, *129*, 668-676.
32. Ellis, H.; Mitchell, R., Self-Grading in a Project-Based Software Engineering Course. *Software Engineering Education & Training*, 2004; Pp 138-143.
33.. Thamhain, H. J., Managing Innovative R&D Teams. *R & D Management* 2003, *33* (3), 297-311.
34. Besterfield-Sacre, M.; Shuman, L.; Wolfe, H.; Yildirim, P., Development of a Work Sampling Methodology for Behavioral Observations: Application to Teamwork. *Journal of Engineering Education* 2007, *96* (4), 347-357.
35. Laub, J. A. Assessing the Servant Organization: Development of the Servant Organizational Leadership Assessment (SOLA) Instrument. Florida Altanitc University, Boca Raton, FL, 1999.

36. Rauch, K. Servant Leadership and Team Effectiveness: A Study of Industrial Manufacturing Correlation. Indiana Wesleyan University, 2007.
37. Gugliemino, P.; Guglielmino, L.; Long, H., Self-Directed Learning Readiness and Performance in the Workplace: Implications for Buiness, Industry and Higher Education. *Higher Education* 1987, *16*, 303-317.
38. Litzinger, T.; Lee, S.; Wise, J., Engineering Students' Readiness for Self-Directed Learning. *American Society For Engineering Education Annual Confernce and Exposition*, Salt Lake City, UT, 2004.
39. Field, L., An Investigation ainto the Structure, Validity, and Reliability of Guglielmino's Self-Directed Learning Readiness Scale. *Adult Education Quarterly* 1989, *39* (3), 125-139;
40. Field, L., Guglielmino's Self-Directed Learning Readiness Scale: Should It Continue To Be Used? *Adult Education Quarterly* 1990, *41* (2), 100-103.
41. Engineering Research and America's Future: Meeting the Challenges of a Global Economy. National Academies Press: Washington, D.C., 2005; *Research and Development: Essential Foundation for US Competitiveness in a Global Economy-A Companion to Science and Engineering Indicators*; The National Science Foundation: 2008.
42. National Science Foundation Innovations In Engineering Education, Curriculum, And Infrastructure Program Announcement 08-610. 2008.