Development of a Leadership, Policy, and Change Course for Science, Technology, Engineering, and Mathematics Graduate Students

Monica F. Cox Purdue University
Carlotta A. Berry Rose-Hulman Institute of Technology
Karl A. Smith Purdue University

Abstract

This paper describes a graduate level engineering education course, "Leadership, Policy, and Change in Science, Technology, Engineering, and Mathematics (STEM) Education." Offered for the first time in 2007, the course integrated the perspectives of three instructors representing disciplines of engineering, education, and engineering education. Included within this paper is justification for creating such a course for STEM graduate students, information about current efforts to integrate leadership and policy in engineering programs, descriptions of the course units and course deliverables, and lessons learned by course instructors. Authors acknowledge the difficulties of co-teaching such a course and of introducing students within technical disciplines to social sciences content and educational practices. Positive aspects of course development include opportunities to engage students in conversations about STEM policy and to create new literature integrating STEM concepts and leadership, policy, and change principles. Suggestions for creating a course at other universities are provided.

Keywords: Leadership, Policy, Change, Engineering Education

I. INTRODUCTION

The Engineer of 2020 reports that "by 2020, we aspire to educating engineers who will assume leadership positions from which they can serve as positive influences in the making of public policy and in the administration of government and industry" [1, p. 50, NAE]. In addition, the National Association of Colleges and Employers (NACE) 2007 Job Outlook reports that employers are looking for candidates who have in-class and out-of-class leadership experience [2]. Despite these recommendations, Vandeveer [3] found that many undergraduate students within engineering departments do not receive the leadership or management skills that are needed for them to succeed as leaders within future engineering positions. If the engineering profession is to define its own future, it must take a leadership role in creating broad-based technology leaders who can work in technical endeavors and can understand and apply the principles of leadership and practice in industry, government, education and nonprofit organizations. In addition, these engineers must acknowledge the significance of public service and accept the challenge of bridging public policy and technology beyond the past connections [1].

As engineering becomes more intertwined in all aspects of life including business competitiveness, military strength, health, and standard of living, there also needs to be a convergence between public policy and engineering [1]. Engineers must be able to develop the infrastructure to support policy decisions with respect to the environment, energy, health care, education or national defense. In addition, via connections to public policy through professional societies, think tanks, or political arenas, engineers must leverage available resources, human and social infrastructures. Assuming leadership positions to make positive influences on public policy and in the administration of government and industry, future engineers will be expected to determine how technology will be used based upon government processes that control, regulate and encourage the use of technology. In addition to demonstrating leadership principles and understanding policy, engineers also must have dynamism, agility, resilience and flexibility to adapt to the ever-changing world and technologies. It will be the engineer's ability to learn new things quickly and to apply knowledge to new problems and contexts that will influence how others within the world receive innovations [1].

In response to the growing importance of leadership, policy, and change in the lives of future engineers, engineering education faculty within the School of Engineering Education at Purdue have made deliberate efforts to prepare their graduates for positions in local, national, and international governments, to help them understand how to create policy that would benefit engineers, and to allow them to engage in conversations about change via the development of a graduate-level course, "Leadership, Policy, and Change in Science, Technology, Engineering, and Mathematics (STEM) Education (ENE 695I)." This paper provides an overview of this course as well as other courses and programs that introduce STEM, primarily engineering, students to leadership, policy, and/or change topics. It also presents a justification for the creation of this course along with the lessons learned by course instructors. Finally, conclusions and future work are presented based upon the lessons learned.

II. LITERATURE REVIEW

Although many general leadership or policy programs reside primarily within Colleges of Education or dwell as independent centers that provide access to students across multiple disciplines, a few undergraduate engineering or technology departments offer either a minor or degrees in an area related to leadership. Administered by the Department of Electrical Engineering at Pennsylvania University, a Leadership Minor offers students opportunities to engage in entrepreneurial-related topics [4]. Within Purdue University's College of Technology, students can obtain a degree in Organizational Leadership and Supervision or obtain a certificate in International Leadership [5]. The

Program Location	Name of Program	College (s) Offering Degree	Degrees Offered	Specializations
Carnegie Mellon University (Pittsburgh, PA)	Engineering and Public Policy (EPP)	Engineering	Both a Ph.D. and a double major undergraduate B.S. degrees within the College of Engineering	• Energy and environmental systems • Information and communication technology policy • Risk analysis and communication • Technology policy and management
University of Maryland (College Park, MD)	Master's of Engineering and Public Policy (MEPP)	Offered jointed between the College of Engineering and the School of Public Policy	Master's	Engineering & • Energy Policy • Environment Policy • Infrastructure Policy • International Development Policy • International Development Policy • National Security Policy • Manufacturing Policy • Biotechnology Policy.
Massachusetts Institute of Technology (Cambridge, MA)	Technology and Policy Program (TPP)	Housed in the Engineering Systems Department; combines perspectives of engineering, humanities, and management	M.S. in Technology and Policy (equivalent to a Master's in Engineering and a Master's in Policy) and a Ph.D. in Technology, Management and Policy	No particular specialization is required.
McMaster University (Hamilton, ON, Canada)	Master of Engineering and Public Policy (MEPP)	Housed in the School of Engineering Practice	Master's	• Environment • Energy • Transportation • International affairs • Infrastructure • Manufacturing • Information Technology • Others topics selected by students

Table 1- North American Graduate Engineering and Public Policy Programs [10]

University of Central Florida offers an Engineering Leadership and Management minor within its Industrial Engineering and Management Systems Department [6], and the University of Maryland offers a minor in engineering Leadership and Development within its College of Engineering [7].

There are also several graduate programs that focus upon leadership and policy, particularly within engineering. Many of the courses in these programs require students to obtain a bachelors or a master's degree in engineering or a related field before being admitted to the program. Two such graduate leadership programs include the Gordon Engineering Leadership Program at Northeastern University [8] and Purdue University's Master's specialization in Engineering Management and Leadership [9]. Northeastern University's one-year graduate program has a mission of "building a future corps of engineering leadership professionals," or Gordon Fellows, who are sponsored by either industry or through the National Science Foundation-funded Bernard M. Gordon Center for Subsurface Sensing and Imaging Systems, and Purdue University's program is a distance education program that allows professional engineers to supplement their Masters of Science degrees in Engineering.

The American Association for the Advancement of Science (AAAS) lists four North American universities that house Engineering and Public Policy graduate programs- Carnegie Mellon University; the University of Maryland, College Park; the Massachusetts Institute of Technology; and McMaster University [10]. A summary of the programs, their degree offerings, and degree concentrations are located in Table 1.

III. THE COURSE

In response to the aforementioned policy recommendations as well as studies highlighting the importance of students' understanding leadership, policy, and change *before* they enter the STEM workforce, a graduate-level course, ENE 695I was developed. This course was comprised of three distinct units (leadership, policy, and change) and was created to focus upon student exploration of these topics. It was introduced at Purdue in fall 2007 and brought together the expertise of education and engineering instructors. The instructors met weekly to discuss the content, in-class activities, and assignments and planned what content would be presented by which faculty member prior to the course meeting. Since the course was team-taught, all faculty attended each weekly session and engaged interactively in the course throughout the semester.

Similar to the courses and programs described in the previous section, ENE 695I (1) included the application of leadership principles within academia and industry; (2) introduced leadership, policy, and change topics to students pursuing degrees in engineering, science, technology, mathematics, *and* education, and (3) made connections between course topics and students' disciplinary interests. ENE 695I, however, differs from the program in Table 1 since it provides an alternative for students who do not want to pursue a graduate degree in engineering and public policy. As one of six core classes required by engineering education Ph.D. students within Purdue's School of Engineering Education, ENE 695I allows students to apply leadership, policy, and change principles as they relate to areas such as design, cognition, pedagogy, and assessment. Because of its focus upon the application of STEM principles, students outside of the School of Engineering Education were recruited into the class, resulting in an initial course comprised of fourteen students- six engineering education doctoral students, one science education student, one industrial technology doctoral student, one engineering Master's student, and five engineering doctoral students.

A. Content Overview, Grading Policy, and Recruitment

The first and only course of its kind at Purdue's College of Engineering, ENE 695I is framed around a historical and current perspective of STEM policy across various educational domains (e.g., secondary and postsecondary), political organizations (state and national governments), and types of professions (e.g., students, teachers, and policymakers) The course included lectures, experiential exercises, discussion, group presentations, videos, individual assignments, and team assignments. As a result of taking this course, participants were expected to do the following:

- Understand the theory, research, and practice of leadership and policy,
- Develop new ways to think about the leadership process, policy implementation, and change,
- Explore factors that contribute to effective and ineffective leadership within STEM organizations,
- Explore and understand the political and policy dimensions of leadership via theoretical approaches to political and policy analysis,
- Investigate the roles of STEM policy at local, state, national, and international levels,
- Develop skills in analyzing policy alternatives and selecting "solutions" within the STEM education domain, and
- Explore negotiation strategies and ways to implement change within STEM environments

Over the course of the semester, students were introduced to three units related to leadership, policy, and change. Table 2 details the weekly schedule of the course and the order of the unit presentations. Each of these units is described in greater detail in the next portion of the paper. Course activities and assignments and the respective weights were: in class participation (7.5%), seminar attendance/ five-minute in-class presentation (2.5%), current event assignments (5%), leadership paper (15%), group policy exploration (20%) and preparation documentation (5%), change deliverable (15%), and a synthesis paper and presentation (30%).

In order to not only target engineering students, instructors disseminated information about the course across campus. As a result, master's and doctoral students from the Col-

Week	Topic	Week	Topic
1	Introductions, course syllabus, course overview, and introduction to leadership, policy, and change	9	Policy Implementation II
2	Leadership I	10	Change I
3	Leadership II	11	Spring Break (No Class)
4	Leadership Process I	12	Change II
5	Leadership Process II	13	Change III
6	March 8: Change I	14	Synthesis of Course Topics
7	Policy II	15	Presentations
8	**Policy Implementation I**	16	Presentations
		17	Presentations

Table 2- Weekly Schedule for the Leadership, Policy, and Change Course

leges of Engineering, Technology and Education enrolled in the course, thereby allowing students to engage in conversations related to industry as well as academia. Additionally, students were encouraged to work with students from other majors in order to experience diverse perspectives regarding the related topics.

B. Leadership Unit

Given the lack of empirical leadership studies explored solely within the context of engineering (and particularly STEM education), course instructors used both education and business references [11-14] to introduce students to historical and modern definitions of leadership, to leadership frameworks and leadership styles (e.g., transformational leadership, transactional leadership, and "Level 5" leadership), and to case studies of leadership and their applications to STEM topics. Students were asked to synthesize materials each week to gain a comprehensive view of leadership, especially related to STEM disciplines. Using interactive activities that allowed students to classify the leadership and management styles at different levels (e.g., local and national), within different contexts (e.g., universities, departments, and governmental agencies), across disciplines, and at different points in history, instructors stretched students' views of leaderships and asked questions such as, "Are leaders born or made?," "Can a person be both a leader and a manager?," and "Is it better to be a leader or a manager?" Using cases of different national and international leaders [15], course instructors asked students to write an eight-page paper applying all leadership readings within a higher education case study. In addition, students were asked to reflect upon their personal leadership styles relative to this case.

C. Policy Unit

In response to national and international calls for STEM policy changes [1, 16, 17], instructors introduced students to an examination of policies that affect formal and informal educational constituents within preschool-12 (P-12) STEM education and higher education; the impact of policies upon diverse stakeholders; and the implementation and analysis of policy. Among the readings assigned to students included NAE's *Engineer of 2020* and Building Engineering and Science Talent's The Quiet Crisis [16, 17]. In addition, students engaged in interactive policy activities during class. Using constructive controversy, a process by which students engage in iterative discussions about pros and cons of an issue and reach a reasoned judgment about final perspectives related to a topic [18], students analyzed a policy suggestion, discussed the positive and negative aspects of each suggestion during class, and identified stakeholders affected by each policy within the *Engineer of 2020's Prospectus*. Three of the NAE topics used within the constructive controversy session included the following [19]:

- The globalization of economic systems and the interconnectedness of its component parts
- Growing concerns about the social and political implications of rapid technological advances and their uneven application among different constituent groups (e.g., the digital divide, medical ethics, etc.)
- The increasing number of engineers working in nontraditional areas that require technological competence and/or fluency (e.g., management, finance, marketing, public policy, etc.)

Context	Topic
Higher Education	• Current tenure policy • Student leadership associated with the Purdue Society of Professional Engineers (PSPE) • The development of the School of Engineering Education • The Engineering Projects in Community Services (EPICS) program • The Purdue Graduate Student Government • 50th Anniversary of the Gamma Pi chapter of Kappa Kappa Psi National Honorary Fraternity for College Bandsmen at Purdue
K-12 Education	• Super Saturday/Summer and Summer Residential programs within the Gifted Education Resource Institute (GERI) programs
Industry	• The implementation of a new file and data management system at Forge Industrial Engineering company
Non profit	• The policies associated with BoilerMaker Aquatics, a local swimming organization

Table 3- Classification and List of Topics Taught in the Course

D. Change Unit

After introducing students to possible applications of leadership and management within STEM education and exposing them to current STEM policy initiatives, instructors allowed students to explore power, politics, and influence in a variety of relationships and to negotiate agreements and difficult conversations. Assigned readings explored change management [20], collective action [21], and engineering change [22]. As a deliverable for this portion of the course, students were asked to conduct a reflection and assessment of leadership, policy or change in an organization or context with which they were familiar using the strengths, weaknesses, opportunities, and threats (SWOT) analysis format [23]. Final topics covered a breadth of topics and are grouped by context in Table 3 below.

E. Synthesis Projects

Similar to the change assignment, students created a synthesis project within the course. Course instructors encouraged students to select topics of personal interest, topics that would inform their current research or jobs, or topics that would allow them to expand their horizons. Suggested deliverables included the creation of workshop materials, the synthesis of literature within a chosen area, or the development of a research proposal. Given these suggestions, one student completed a research proposal, and the remaining students provided overviews or syntheses of current literature. A final list of topics is found below.

- "Waking the Sleeping Giant (Latinos): An Approach to Examine Family Values"
- "American Society of Civil Engineers' Body of Knowledge: Understanding the Policy and Considering the Impact"
- "The Role and Development of Leadership Abilities within the Engineering Projects in Community Service Program"
- "Answering the Call to Reform Engineering Education in the United States: The Current Status and Proposed Model for Change"
- "Knowledge Management and the University"
- "Institutional and Curricular Policies to Improve Student Retention in STEM Education"
- "Is Science Ready for No Child Left Behind?"
- "Skills GAP Shortage in Manufacturing and How Government is trying to address the Problem"
- "Engineering K-12 Programs: An Overview"
- H-1B Quotas: Educating and Exporting some of America's Best Educated"

IV. LESSONS LEARNED

Faculty teaching the course learned several lessons by the end of the first year. These lessons related to pedagogical perspectives about the course, preparation and development of course materials, and basic organization of a course placed within a College of Engineering. Using the SWOT approach, lessons learned representing perspectives from the three course instructors are presented in Table 4.

V. DISCUSSION

Although such a course is needed to engage students pursuing technical degrees in leadership, policy, and change topics, ease of implementation of such a course may vary depending upon several factors. First, course instructors must be comfortable working with

Category	Instructors' Perspectives
Strengths	• Ability to co-teach a course with faculty who have different perspectives and expertise
Weaknesses	• Many engineering students have not had to read extensively, and it was difficult to engage them in initial readings
Opportunities	• Engage STEM students in deep conversations about leadership, policy, and change while they are enrolled in graduate school • Engage students in conversations with STEM leaders, policymakers, and change agents
Threats	• Lack of empirical research and resources that integrate STEM education and leadership, policy, and change • STEM students and administrators not recognizing the need for teaching such topics to STEM graduate students

Table 4- Lessons Learned from Course Instructors

course content within the realm of STEM disciplines. This means that education faculty who traditionally might teach such a course must be familiar with the issues facing STEM education, and technical faculty who might develop such a course must be cognizant of empirical research studies and theories within general leadership, policy, and change literature. For this reason, the authors recommend a teaching partnership between STEM and education faculty with interests in course topics.

In addition, instructors need to anticipate the apprehension that STEM students might have about enrolling in a reading-intensive course. Since STEM students enrolled in the course may not have ever read social science articles, instructors might give students a primer about ways to engage in course content and read such large volumes of material. Also, instructors might clarify their expectations for writing assignments early in the semester. In this way, the students should feel more comfortable synthesizing leadership, policy, and change literature and applying such content to their respective areas.

Finally, the course described in this paper is a core course that could provide the foundation for graduate-level and undergraduate concentrations in leadership, policy, and change within Colleges of Science, Technology, and Engineering. Additional courses could apply leadership, policy, and change principles in a variety of contexts (e.g., industry, government, and academia) and could explore certain topics (e.g., policy creation) in more detail. In addition, students might engage in leadership, policy, or change practicums in which they spend a semester applying course principles across diverse environments (e.g., university leadership and state and local governments).

VI. CONCLUSIONS

By creating curricula that reflects the rapid pace of change in the world and its unpredictability and by including non STEM topics within this curriculum, educators are increasing students' abilities to engage in lifelong learning [1]. More specifically, educators need to involve student-centered education with better alignment between engineering curricula and academic experiences [2]. The course described in the paper does just that by addressing national and international calls for exposure of STEM students to topics in leadership, policy, and change. Although three faculty began course development based upon their exposure and interests in the three major course topics, they incorporated students' interests and expertise in the revision of course materials throughout the semester, thereby allowing students to engage in deeper conversations about the relationship between their technical work and national and international STEM issues. The authors anticipate that a course such as the one described in this paper will serve as a model for engaging STEM graduate students, educators, and policy makers in deep conversations about not only policies but ways that these policies impact its stakeholders.

ACKNOWLEDGEMENTS

The authors would like to acknowledge Dr. Cordelia Brown for her contributions to the content of the course.

BIBLIOGRAPHY

[1] National Academy of Engineering, *The Engineer of 2020: Visions of Engineering in the New Century*, National Academies Press, Washington, DC (2004).

[2] National Association of Colleges and Employers (NACE) *Job Outlook 2007*. <http://naceweb.org/products/info_pages/joboutlookreport.htm>, accessed 7/15/08.

[3] R.C. Vandeveer, Gap Management: Balancing Engineering Education and Leadership Skills Development, <http://www.vantechtraining.com/publications/ASEM%20Gap%20Management%20Revised.doc>, accessed 8/1/08.

[4] L.C. Burton, J.V. Matson, and J.G. Soper. "The Engineering Leadership Development Minor at Penn State, Proceedings of the 1996 ASEE Annual Meeting, Session 2432, (1996).

[5] Purdue University Department Organizational Leadership and Supervision, <http://www.pnc.edu/ols/index.html>, accessed 8/1/08.

[6] A. Ferreras, E. Hampton, K. Williams, L. Crumpton-Young, L. Rabelo, P. McCauley-Bell, S. Furterer, The Development of a Curriculum to Instill Engineering Leadership and Management Skills in Undergraduate Students, Proceedings of the 2006 ASEE Annual Conference and Exposition, (2006).

[7] University of Maryland Minor in Engineering Leadership Development, <http://www.ursp.umd.edu/leadership-minor/minor-leadership.html>, accessed 8/1/08.

[8] The Gordon Engineering Leadership Program at Northeastern University, <http://www.censsis.neu.edu/gordonfellows/>, accessed 8/1/08.

[9] Purdue University Engineering Professional Development, <https://engineering.purdue.edu/ProEd/credit/eml>, accessed 8/1/08.

[10] American Association for the Advancement of Science (AAAS), Engineering/Public Policy Programs, <http://www.aaas.org/spp/sepp/sepslpc.htm>, accessed 8/1/08.

[11] B.M. Bass, From Transactional to Transformational Leadership: Learning to Share the Vision, *Organizational Dynamics*. 19-31 (1990).

[12] J. Collins, Level 5 Leadership: The Triumph of Humility and Fierce Resolve, *Harvard Business Review*. 83, 136-146 (2005).

[13] J.P. Kotter, What Leaders Really Do, *Harvard Business Review*. 79, 85-96 (2001).

[14] J.S. Fleming, The Eisenhower College Silver Dollar Legislation: A Case of Polities and Higher Education, *The Journal of Higher Education*, 57, 569-605 (1986).

[15] H. Gardner, and E. Laskin, *Leading Minds: An Anatomy of Leadership*, BasicBooks: New York, NY (1995).

[16] E. Seymour, Tracking the Processes of Change in U.S. Undergraduate Education in Science, Mathematics, Engineering, and Technology, *Science Education*, 86, 79-105 (2002).

[17] S.A. Jackson, *The Quiet Crisis: Falling Short in Producing American Scientific and Technical Talent*, Council on Competitiveness, Washington, D.C. (2005).

[18] D.W. Johnson, R. T. Johnson, and K.A. Smith, Constructive Controversy: The Educative Power of Intellectual Conflict, *Change*, 32, 28-37 (2000).

[19] National Academy of Engineering Committee on Engineering Education, The Engineer of 2020 Project Prospectus, <http://www.nae.edu/nae/engeducom.nsf/0754c87f163f599e85256cca00588f49/85256cfb004a463885256ed800550afd/$FILE/2020%20Prospectus.pdf>, accessed 8/1/08.

[20] R.H. Axelrod. Why Change Management Needs Changing, *Reflections*, 2, 46-57 (2001).

[21] T.J. Hargrave, and A.H. Van de Ven, A Collective Action Model of Institutional Innovation, *The Academy of Management Review*, 31, 864 (2006).

[22] J.D. Bransford, Preparing People for Rapidly Changing Environments, *Journal of Engineering Education*, Guest Editorial, (2007).

[23] Albert Humphrey's TAM Model. <http://www.businessballs.com/alberthumphreytam.htm>, accessed 8/15/08.

Monica F. Cox, Ph.D., is an Assistant Professor in the School of Engineering Education at Purdue University. Her research interests include the development and validation of engineering education assessment tools; assessment of engineering doctoral education; undergraduate and graduate students' acquisition of engineering norms, skills, and attributes within academia and industry; and assessment of pedagogy within engineering classrooms and laboratories. She is a recipient of a 2008 National Science Foundation Early Faculty Career (CAREER) grant and of a Presidential Early Career Award for Scientists and Engineers (PECASE).

Dr. Carlotta A. Berry is an assistant professor of Electrical and Computer Engineering at Rose-Hulman Institute of Technology (RHIT). Her research interests include human-robot interaction and interfaces and engineering education innovation. She is a co-PI on the RHIT multidisciplinary educational robotics initiative which seeks to involve students from multiple disciplines in engineering and science in collaborative work and study.

Karl A. Smith is Cooperative Learning Professor of Engineering Education, School of Engineering Education, at Purdue University West Lafayette. He has been at the University of Minnesota since 1972 and is in phased retirement as Morse-Alumni Distinguished Professor of Civil Engineering. He has been actively involved in engineering education research and practice for over thirty years. He is a Fellow of the American Society for Engineering Education and past Chair of the Educational Research and Methods Division, and Editor-in-Chief of the Annals of Research on Engineering Education. Karl has worked with thousands of faculty all over the world on pedagogies of engagement, especially cooperative learning, problem-based learning, and constructive controversy. He has co-written eight books including Active Learning: Cooperation in the College Classroom, 3rd Ed., Cooperative learning: Increasing college faculty instructional productivity; Strategies for energizing large classes: From small groups to learning communities; and Teamwork and project management, 3rd Ed.