Engineering Leadership Education – The Search for Definition and a Curricular Approach

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Abstract

While industry and academia agree that leadership skills are critical for engineering graduates, there exists no consensus regarding the definition of "engineering leadership". The engineering leadership development program at Penn State University has a decade-long experience in teaching leadership to engineering undergraduates. In response to faculty review in 2005 changes were made to the existing curriculum within the framework of literature benchmarking and faculty perspectives on engineering leadership as pedagogy. Educational objectives and outcomes were defined and courses enhanced or created to satisfy these needs. The most significant changes to the curriculum were in the area of global leadership.

Introduction

The engineering profession delivers the message that mere technical competency is no longer sufficient for future success; "communication, project management, and leadership skills are becoming more important than ever" [2]. Educators tell us that "as corporations depend increasingly on developing new products, processes and services to be competitive, students' ability to work in and lead groups of people with various backgrounds and cultures… will be a key to success" [28]. Leaders in the field see a future of opportunity "for engineers to exercise their potential as leaders, not only in business but also in the nonprofit and government sectors" and emphasize graduates "must understand the principles of leadership and be able to practice them in growing proportions as their careers advance" [19]. There is clearly a demand for leadership development in engineering students.

What the specific objectives and outcomes of an engineering leadership development program should look like, however, may depend upon the worldview of who you ask. For example, one might argue that the worldview of an industrial defense firm is different from that of a non-governmental organization (NGO), and the attendant priorities and objectives for the respective leadership programs reflective of each. This would not be surprising given the diversity of fields within which engineers practice, at once designing devices which save lives and take lives, creating technology that preserves the environment or results in damage to it. Others maintain that "morally creative leadership - leadership that is effective in moving groups toward morally desirable goals…can be shown by individuals, corporations, nonprofit organizations, and government" [16]. Some argue more fundamentally that although leadership must be taught, specific leadership personality, style or traits simply do not exist [13]. And so it seems, with thousands of books on the subject, and new publications arriving each day, "[d]espite the plethora of attention, the concept of leadership remains paradoxically obscure" [14].

Engineering leadership education programs in U.S. universities, while able to rely in part on fundamental traditions of leadership pedagogy, are also confronted with discipline specific needs and a rapidly changing world. The practice of engineering has become increasingly global. The design and management of projects are spread across time zones and cultures while U.S. engineering graduates only account for 5-6% of the annual global minting; this trend is predicted to continue. University students currently in the educational pipeline have generational characteristics which uniquely define them; a new generation (i.e. generation Z) is predicted to arrive soon with its own generational identity, needs and worldview. Program faculty may also hold a diversity of worldviews that can affect their curricular interpretation and prioritization.

This paper presents the pedagogical model of the Engineering Leadership Development Minor (ELDM) at Penn State, the results of a 2005 curriculum review and subsequent evolution.

The Penn State model – 20th century

The ELDM at Penn State was a product of the Leonhard Center whose mission is to enhance engineering education at the university. Plans for the ELDM began in 1995, courses were piloted in 1997 and the minor graduated its first students in 1999. The ELDM has since graduated over 500 students, ~90% of whom were from the college of engineering, and ~30% females. The goals (i.e. educational objectives) in 1995 were to: (1) enhance communication skills; (2) enhance ability to work effectively in teams; (3) enhance ability to think innovatively; (4) provide an understanding of the nexus between engineering and business.

The ELDM curriculum today still consists of the same 12 required core credits (Figure 1) and 6 credits of approved supporting courses

The course descriptions and broad objectives for the core ELDM curriculum appear below:

ENGR 408 – Leadership Principles

This introductory course focuses on leadership concepts, principles, theories and relevant literature. In addition to providing students with an academic foundation in leadership, the course emphasizes oral and written skills development and encourages each student to identify and develop their own unique leadership skills and styles. Focus is placed on communication styles, leadership techniques, project management, and working in a global context. Course topics include: (1) leadership theory; (2) understanding of oneself and others; (3) judgment and moral courage; (4) the role of innovation and sustainability in technical leadership; (5) leading change.

ENGR 493 – Leadership Experience

This course serves as a "laboratory" complement to ENGR 408 (Leadership Principles). Students are expected to observe, apply, and reflect on topics covered academically in ENGR 408 while working on real world projects. Students select projects and work with industrial and community clients domestically and overseas gaining real-life leadership and project management experience while making a positive impact on the world.

ENGR 409 - Leadership in Organizations

This course is intended to help students develop a deeper global understanding of the important facets of ethical leadership in organizations and how they relate to business in the technology field. The course includes the analysis of best practices of exemplary organizations, as well as a review of continuous improvement methodologies. Often referred to as a "Mini MBA", this course touches on the following topics: (a) dimensions of leadership; (b) strategic planning; (c) marketing; (d) finance; (e) human resource management; and, (f) process improvement.

ENGR 407
– Technology-Based Entrepreneurship

This course focuses on developing skills that lead to a high level of individual and group creativity. Through participation in a series of exercises students have the opportunity to discover and expand upon their innate creativity. The specific exercises are focused on developing new products and new businesses. Basic business concepts are addressed, specifically the skills that are most important to an entrepreneur or business leader. Among the course goals is the desire for students to learn creative approaches to solving tough problems, as well as understanding the importance of embracing failure as a critical ingredient in learning how to succeed as an entrepreneur and as a leader.

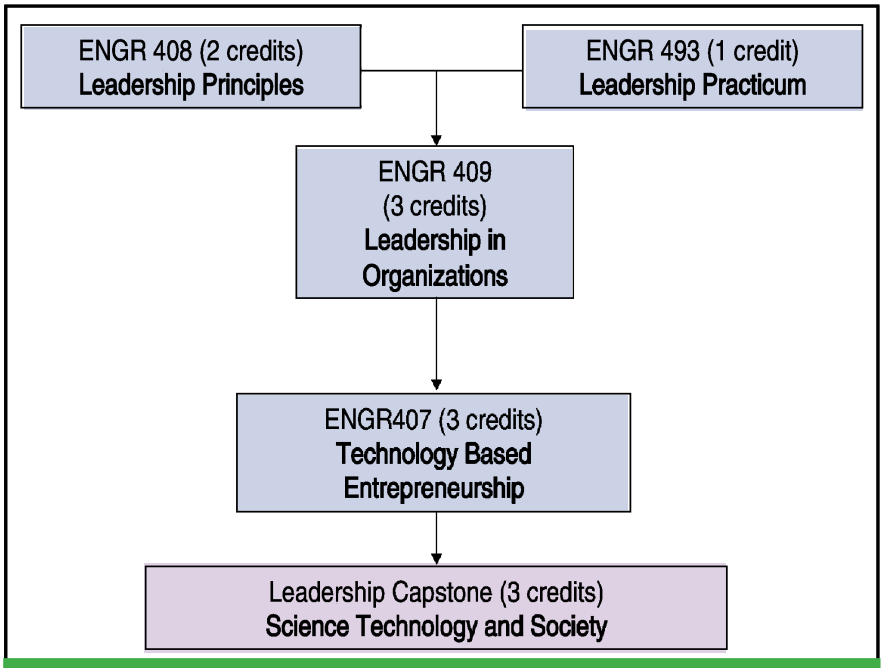

Figure 1 – Core ELDM curriculum

Science Technology and Society (STS) Capstone

The capstone for the program is "Science, Technology and Public Policy" (STS 460). The aim of this course is for students to gain an understanding of how public policy shapes science and technology and how science and technology shapes public policy. The issues involve a cross-section of institutions: business, legal, academia, and government. They also involve a range of processes and mechanisms. Processes include bureaucratic decision-making, public involvement forums, and litigation. Mechanisms include R&D tax credits and intellectual property protection. Because the issues discussed are interdisciplinary, analyses draws upon many different disciplinary knowledge bases including but not limited to economics, political science, sociology, psychology, communications, law, and ethics as well as from the sciences and engineering.

Benchmarking educational objectives and outcomes for the 21st century

In 2005-2006 the Penn State program underwent an internal curriculum review by its faculty. Academic programs are founded upon

Leadership Theories/Principles	Reference
(1) Trait theory and other psychological approaches; (2) group and team leadership; (3) situational leadership theories; (4) organizational development, change and leadership; (5) leadership vs. management; (6) politics, power and leadership; (7) charismatic leadership; (8) vision, human condition, and leadership; (9) leadership formulas; (10) ethical leadership; (11) leadership in limited time and space; (12) multicultural and global leadership.	[24]
(1) A strong understanding of the principles of sustainability, (2) integrate this understanding within a global perspective. Note: The importance of integrating sustainability within engineering curricula has been discussed by others with a variety of suggested strategies.	[17] [8], [27], [3]
(1) Leadership principles (e.g. human behavior, personality, leadership styles, ethical leadership, etc.); (2) leadership tools (e.g. effective communication, conflict resolution, etc.); (3) leadership research and presentation.	[7]
Big picture thinker. Whole system thinker	[4] [10]
Leadership is defined through self-discovery and experience. Leaders should be viewed as artists instead of managers.	[20]
Leadership Attitudes	
(1) Continually learning; (2) service oriented; (3) radiate positive energy; (4) believe in other people; (5) lead balanced lives; (6) see life as an adventure; (7) synergistic; (8) exercise for self renewal.	[5]
Leadership Behaviors	
(1) Able to communicate a shared vision; (2) demonstrating integrity; (3) focusing on results; (4) ensuring customer satisfaction.	[11]
(1) Management of virtual team task and relationships; (2) clearly communicating virtual team vision, goal(s) and outcome(s).	[23]
(1) Integrity and character; (2) leading by example; (3) responsibility; (4) purpose, passion and ambition; (5) credibility; (6) visibility and personal presence; (6) expertise and competence.	[21]
(1) Big thinker; (2) ethical and courageous; (3) masters change; (4) risk taker; (5) mission that matters; (6) decision maker; (7) uses power wisely; (8) team builder; (9) good communicator. Note: The authors maintain that "leadership for engineers is more complicated than most other sectors because, in addition to the traditional skills needed to excel, an additional dimension of technological leadership and governance is required".	[9]
Leadership Skills	
(1) Demonstrating organizational commitment; (2) providing direction; (3) promoting change; (4) structuring work; (5) managing organizational effectiveness; (6) strategic problem solving; (7) interpersonal communication and motivation; (8) team management; (9) stakeholder orientation; (10) conflict management.	[15]
(1) Function in multi-disciplinary teams; (2) understand professional and ethical responsibility; (3) communicate effectively; (4) understand the impact of engineering solutions in a global, economic, environmental, and societal context; (5) recognize the need for lifelong learning; (6) have knowledge of contemporary issues.	[25]

Table 1: Leadership literature benchmarking

educational objectives with defined expected outcomes and it is with this definition that our faculty wrestled. The curricular definition process is challenging enough for a traditional engineering program such as civil engineering which has a strong history and relatively unambiguous definition; it is even more so for engineering leadership development, an academic pursuit relatively new to academia whose fundamental definition can be clouded by subjectivity and the volume of views and published literature on the topic. A common pedagogical approach in leadership education is to define what it is that leaders do (i.e. traits), and have students learn from and strive to emulate these traits. So what quintessential traits embody engineering leadership? Presented here is an illustrative sample from benchmarking views on leadership from a broad diversity of sources as an example of the type of material used by our faculty in its search for definition, including more recent germane literature on the topic (Table 1).

Creativity, innovation and change have been important elements within the Penn State program from its inception. Coursework was designed specifically to promote creative thinking and innovative action as these were considered integral to being at the forefront of engineering (i.e. an engineer leader). One traditional worldview tells us that leadership and creative people are mutually exclusive; creative people do not need to be led because of the inherent qualities that make them creative [20]. Other views define attributes necessary for the leadership

Leadership style	Reference
(1) Idea generation and facilitation; (2) idea structuring - setting expectations, providing guidance and integration; (3) idea promotion - using networks to promote the project and obtain necessary resources.	[18]
Leadership behaviors	
(1) Skill in communication and interpersonal interaction; (2) ability to obtain useful and timely information about project progress; (3) openness and appreciation for subordinate's ideas; (4) empathy for subordinate's feelings and ability to provide recognition; (5) skill at using personal networks to transmit and receive information germane to the project.	[1]
Leadership activities	
(1) Sense-maker - learns by doing, interprets, frames and builds a shared vision; (2) web-weaver - identifies and leverages talent, establishes communication, mediates between worldviews; (3) game-master - makes the rules, delivers sanctions and rewards; (4) flow-balancer - challenges, motivates, believes in fun.	[26]

Table 2: Creative leadership literature benchmarking

of creative teams. Examples from literature benchmarking are presented above (Table 2)

Reviewing literature germane to engineering leadership as part of the benchmarking process provided valuable insights from the community regarding content and delivery. More importantly, this process prompted introspection about the program status quo and vigorous discussion about the future.

ELDM educational objectives and outcomes

Faculty review and discussion led to the development in 2006 of a suite of defined educational objectives and outcomes. The qualities compiled by the faculty as navigation aids in this development consisted of the following:

I. Core leadership qualities: (1) able to formulate a vision; (2) effective communicator; (3) morally courageous; (4) results oriented;
II. Global leadership qualities: (5) global citizen; (6) proficient with collaborative technologies; (7) able to build and maintain cross-cultural partnerships and alliances;
III. 21st century leadership qualities: (8) technically broad; (9) versatile; (10) innovative; (11) understands risk.

The educational objectives and outcomes arising from faculty discussion about the dimensions of these qualities (i.e. I-III above) appear in Table 3 and Table 4.

Enhancements and amendments to the curriculum

The identification of the 18 objectives and outcomes in Tables 3 and 4 and curriculum mapping to evaluate how and where objectives were being met led to the re-crafting of pre-existing courses (i.e. ENGR 407, 408, 409) to incorporate or enhance defined educational objectives. The conclusion that the program was lacking in the area of global leadership led to the creation of a two-track ELDM curriculum, one consisting of the core 1995 curricular offerings (re-crafted to include global elements), the other track for courses with a distinctly global focus. The new two track curriculum appears in Figure 2.

The global courses focus on developing a deeper knowledge of the world, enhanced skills in cross-cultural communication, and direct experience in participating in change processes in other countries. Strategic assignments and a curricular emphasis on diversity and global awareness provide an academic foundation. Immersive user-friendly international course sequences provide the tactile learning component.

The program offers two course sequences through which students may elect to collaborate with students from either Hungary (International Entrepreneurship and Organizational Leadership) or Morocco (Leadership, Innovation and Global Resource Challenges) and travel to that country as part of the final component of the sequence. The sequence including collaboration with Hungary replaces Leadership in Organizations (ENGR 409) and the sequence including collaboration with Morocco replaces the Leadership Capstone (STS 460). Both global course sequences begin with the same introductory class offered each fall semester (Global Engineering Teams Seminar) which uses cognitive approaches to global knowledge to create a strong foundation in the dimensions of culture

1. Enhanced communication skills – oral *Students will be able to clearly and confidently introduce, discuss, and recap a topic orally before an audience, often with little or no prior preparation.*
2. Enhanced communication skills – written *Students will be able to acquire, synthesize, clearly author, and professionally package information in a written format.*
3. Enhanced project planning/management, organizational leadership skills *Students will understand that leadership is accomplished by inspiring a sound organization made up of motivated individuals working in teams guided by a shared vision and a clear statement of mission, be able to practice these leadership skills, and be able to write a simple business plan outline.*
4. Enhanced economics skills *Students will understand basic accounting principles, return on investment, and the value of economic growth in developing communities.*
5. Enhanced marketing skills *Students will be alert to opportunities in both high- and low-technology local and global markets, and aware of effective and appropriate regional marketing strategies to employ.*
6. Ability to use metrics to gauge results *Students will understand the value of creating, gaining support for, and using both quantitative and qualitative measures of performance in people, systems and technology.*
7. Enhanced technological savvy and abilities *Students will be able to understand the development and management of technology in local, national, and global settings. They will be literate about technology and innovation in both advanced and developing economies, and understand the environmental constraints of technology.*
8. Ability to share leadership – teamwork *Students will be able to function in an organization of individuals working toward a common creative goal and be able to work in teams involving co-located or geographically distributed participants.*
9. Enhanced creative/innovative ability *Students will understand that the creative use of their engineering skills can create businesses, add value, and improve lives, that innovation is the core strategy of a successful organization and should be developed and encouraged.*
10. Ability to exercise sound judgment *Students will use critical thinking to formulate a sound judgment on a broad range of topics, giving consideration to economics, the environment and society.*

Table 3: ELDM Educational objectives and outcomes – Skills and abilities

and communication while also introducing students to case studies of global leaders and organizations that have made a difference. Approximately 25 students travel each year with the program, representing a significant percentage of the ~50 students who graduate each year with a formal Minor in Engineering Leadership Development.

Students who take International Entrepreneurship and Organizational Leadership begin the spring semester with a 4-week academic foundation in engineering design, project planning and international project management prior to the start of virtual teaming. The students then form virtual teams with business students at Corvinus University in Budapest, Hungary, and begin their collaboration during formal scheduled in-class meetings using classroom Polycom™ videoconferencing, and outside of class using personal Skype™ accounts. Projects are real-world and clients on past projects have been located in Central Europe, Africa, Central Asia, South America and the Caribbean. The Hungarian-American student teams deliver their final presentations during a short intensive trip to Budapest by Penn State students immediately following examinations to allow students to return for summer jobs and/or summer school. Students report increasing value from this international sequence, and significant enhancement to their global skill set [22].

Students who take Leadership, Innovation and Global Resource Challenges begin the spring semester with a 6-week academic foundation of cultural preparation for their visit to Morocco over spring break. This preparation

11. Ethical awareness and conduct *Students will be able to recognize and address ethical challenges, and seek, understand, and resolve differences among stakeholders in decision-making processes.*
12. Self knowledge and awareness - Character *Students will understand personality and temperament, recognize common global character traits, understand the value of introspection and reflection in leadership, and demonstrate high standards of behavior.*
13. Enhanced global awareness/world view *Students will have a an informed and contemporaneous view of the world, be aware that diverse talents and expertise reside in all parts of the world and that its peoples and nations are strongly interconnected, and be able to prognosticate based upon their knowledge of history and current events. Students should understand the roles the United States plays in the world and how diverse peoples view the United States and why.*
14. Enhanced appreciation of cultural diversity *Students will understand the achievements of diverse peoples, be sensitive to cultural differences, and comfortable with alternative world views and diverse ethical principles. They should display inclusive behavior and a commitment to an equitable world.*
15. Understanding/embracing risk-taking *Students will understand the value of intelligent fast failure and be confident in assessing and taking risks.*
16. Understanding of public policy issues *Students will be able to think broadly, seeing issues in a rich context of various alternatives, probabilities, and trade-offs, see engineering as applicable to problem solving in general, and understand the role of public policy in science, technology, and business.*
17. Understanding of contemporary leadership theories *Students will be able to recognize and appreciate different contemporary approaches, viewpoints and theories of leadership.*
18. Understanding of the role of sustainability in engineering *Students will understand that environmental protection does not preclude economic development and that economic development must be ecologically and socially viable now and in the long run.*

Table 4: ELDM Educational objectives and outcomes – Awareness and understanding

includes: studying spoken Moroccan Arabic (Darija), the history of science and engineering in Islam, the history and culture of Morocco, the relationship between Islam, Judaism and Christianity, and regional geopolitics. Over spring break Penn State students travel to Morocco where they live with host families in the old city and study leadership and innovation in the context of resource management and engineering with engineering peers from the Ecole Mohammadia d'Ingénieurs (EMI). Approximately half the academic day is spent in lectures, the other half on field trips or field challenges (students working in multicultural teams to solve challenging engineering-related tasks). The current course sequence focuses on promoting intercultural understanding, raising global awareness, and developing leadership skills and innovative thinking with respect to engineering design in order to better meet the challenges of the 21st century. While in Morocco, students from Penn State form joint design teams with EMI students which they maintain after their return to the US. These teams work initially as separate virtual teams using personal Skype™ accounts and then as a whole for the balance of the semester on an engineering design challenge.

These curricular opportunities were designed to bring a stronger global context to our students' individual undergraduate engineering curriculum, provide a holistic perspective on leadership, and shine a light on current and future global challenges and leadership opportunities, allowing students to hone their critical thinking and interpersonal skills to advanced levels in order to prepare them for innovative graduate work or leadership positions within global organizations. We have striven to provide them with extraordinary learning opportunities in leadership not only through creative, dynamic, interactive classroom activities but also through these hands-on activities across time zones and cultures where they have the chance to collaborate and lead virtual teams with international partners on socially relevant projects, eventually breaking bread with their teammates across the Atlantic.

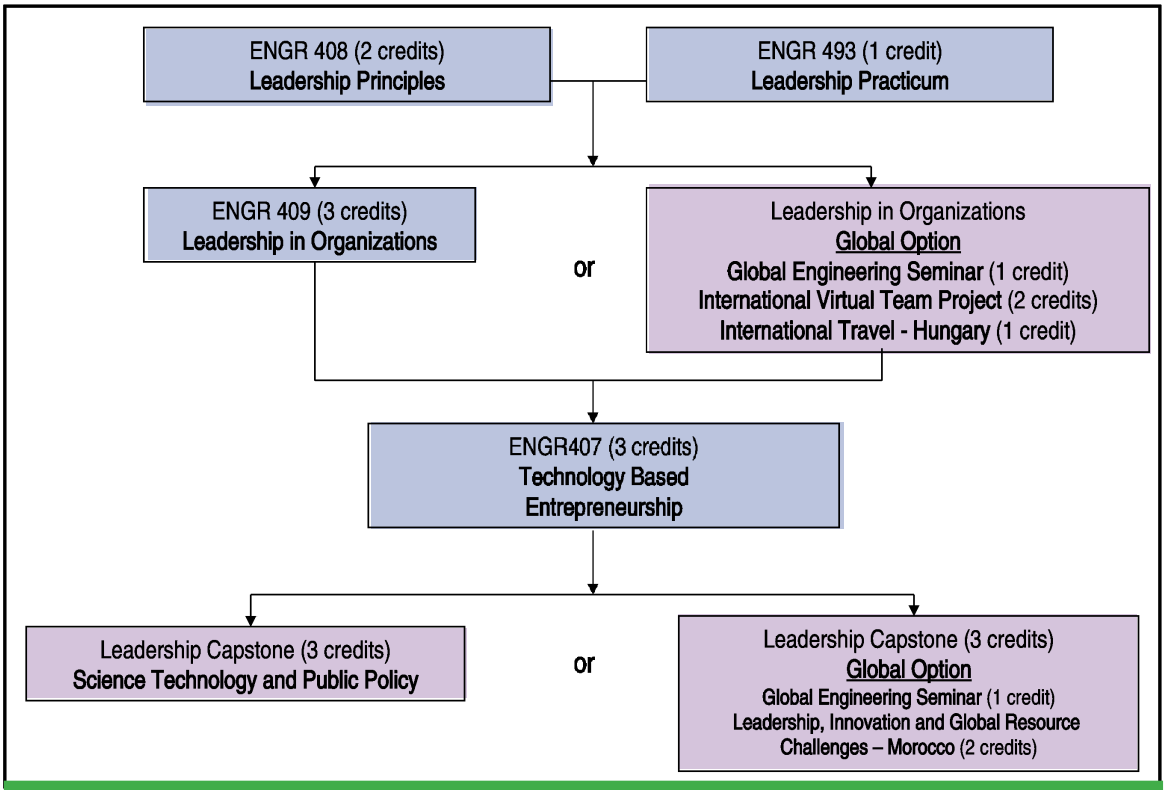

Figure 2 – Globalized ELDM curriculum

Discussion

While the search for defined leadership attributes from sources external to the program (i.e. benchmarking from literature) was a core facet of our curricular development process, the effect of our faculty worldview was perhaps equally important. There exist clear subjective processes inherent in a faculty group sifting through and discussing literature, and although there was agreement on the 18 objectives and outcomes presented in Table 3 and table 4, there was some divergence with respect to ranking their relative importance. On average, however, the faculty identified the five priority themes thought to be definitive of the program as a whole:

I. Global awareness/world view/appreciation for diversity
II. Self knowledge/character/ethics
III. Communication/oral and written
IV. Creativity/Innovation/focus on results
V. Project planning theory and practice/teamwork

In addition to content, the mode of content delivery is equally important. How shall we teach these topics? Murray Gell-Mann says: "We need to move from the sage on the stage to the guide on the side" [7]. Shuman et al proposed that the ABET "soft skills" can only be taught through active, flexible teaching and learning techniques [25]. This observation resonates with that of Parks discussed earlier, where leadership education is more about exploratory discovery by the student than about the brilliant performance of a faculty member [20]. Farr and Brazil echo the adage the leadership cannot really be taught in a conventional sense but it can be learned; they observe that even with well designed engineering leadership curricula and programs in academia and industry, ultimately the responsibility rests on the shoulders of the student to learn [9].

Conclusion

While the study of leadership is considered to be a mature field, engineering leadership education today remains effectively undefined [12]. The 18 educational objectives and outcomes in Table 3 and Table 4, as well as the five core themes in Table 5 are reflective of the current perspective of the Penn State ELDM faculty regarding the pedagogy of engineering leadership education at Penn State. Given another time, another faculty group, these core attributes might change in response to the reality of that time and/or the collective history and worldviews of the faculty team.

This paper presents the view that while engineering leadership education is critical for the development of our students, the search for a definition of exactly what this means is by no means trivial. While the core foundation of leadership education may be timeless, the process of characterizing the objectives and outcomes of an engineering leadership program is as dynamic as the changing world we live in and in the end involves a degree of subjectivity.

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