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Systems Thinking and the Engineering Leader

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What is Engineering Leadership?

"As we look ahead into the next century, leaders will be those who empower others."

--- Bill Gates

"Mission Command is the exercise of authority and direction by the commander using mission orders to enable disciplined initiative within the commander's intent to empower agile and adaptive leaders…it calls for leaders with the ability to build a collaborative environment, the commitment to develop subordinates, the courage to trust, the confidence to delegate, the patience to overcome adversity, and the restraint to allow lower echelons to develop the situation."

---Army's Doctrinal Reference Publication 6-22

A quick review of your local book store will illuminate the multitude of qualifiers to the word 'leadership'. These include authentic, entrepreneurial, democratic, collaborative, genuine, adaptive and transformational to name just a few. Author perspectives certainly drive these descriptors. Business, Strategic, and Technology managers each have unique twists on the secret formula for building 'leadership' competencies. This chapter will stand on the efforts of giants in the literature, but it will also offer a unique point of view on what Engineering Leadership is, and it will frame valued competencies which can be used to develop capacity in young technology focused leaders.

Engineering Leadership (EL) is the enabling and alignment of people, processes, policy and technologies towards achievement of Science, Technology, Engineering, or Mathematic related organizational goals. EL requires technical ingenuity, conceptual thinking, interpersonal effectiveness and ethical grounding to lead multidisciplinary teams in creation of innovative science and technology solutions to solve the most complex of human challenges. Figure 1 captures a Venn diagram of this basic EL model. Investment in development of EL competencies is increasingly important as engineered systems grow in complexity. Unfortunately, "engineers are hired for her or his technical skills, fired for poor people skills, and promoted for leadership and management skills" [1]. Engineering Leadership becomes essential for the engineer or technician as they grow from the design and operations (tactical levels), to project/program management (operational levels), and ultimately enterprise management (strategic levels). These leaders will spend less time on traditional engineering and technology issues and more on the internal business and external client challenges [2]. EL allows for iterative review of internal and external indicators so that he or she can align systems (people, process, policy and technology) towards the organizational goals in an ethical manner through repetitive opportunities to practice through experiential engagements while simultaneously being exposed to theoretical frameworks.

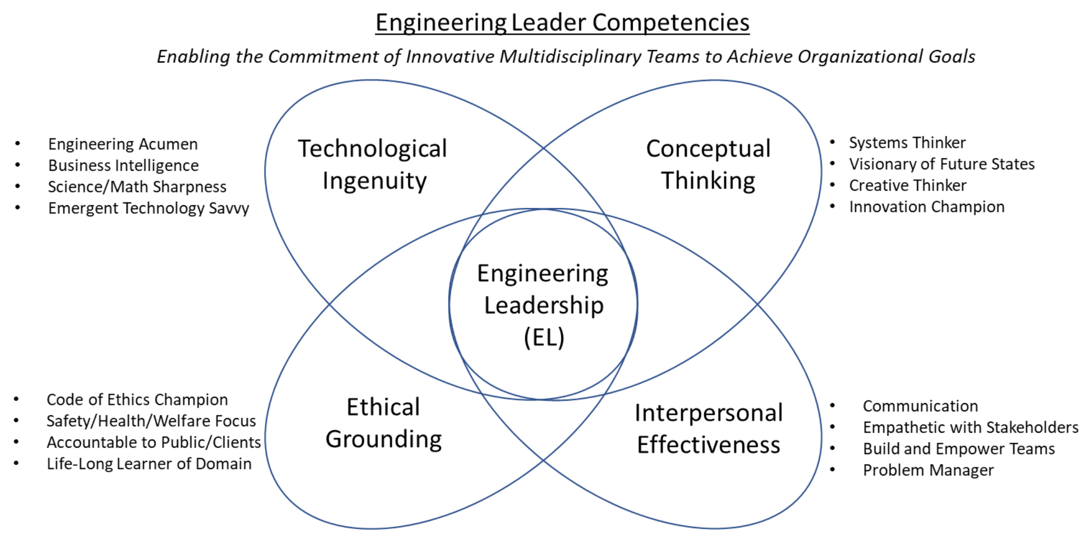

Figure 1: Engineering Leader Competencies.

Consensus on what ‘Leadership’ is, much less ‘Engineering Leadership’, remains elusive. The origin of ‘leadership’ can be traced to the word *leith* which means ‘to go forth and die’ [3]. While some engineering leaders might feel this way literally at times, the essence of the root conveys a greater purpose of inspiring a team towards solutions of a unifying goal or objective.

The United States’ Army War College (USAWC) approach to ‘Strategic Leadership’ presents similar competency domains to that presented in Figure 1 [4]. The USAWC model presents the importance of strategic leadership competencies in an increasingly volatile, complex, uncertain, and ambiguous (VUCA) environment where leaders are required to constantly update their situational awareness of how the environment interacts with a strategy, or system of interest [4]. The integrated competencies are meant for senior U.S. interagency leadership development and rooted in the study of centuries of leadership vignettes. More broadly, Leadership as officially defined by the U.S. Army in the Army Doctrine Reference Publication (ADRP) 6-22, discusses the fundamentals of leadership as the ability to influence, provide purpose and direction, motivate, and constantly improve for the future the organization. Competencies include ones of character, presence, and intellect which enable leadership, development of subordinates, and achievement of goals. Development of competencies come from a balance of schooling, intrinsic motivation to develop oneself, realistic training, and professional experience [5]. The 'bins' of leadership competencies described by the manual are closely integrated throughout the USAWC model.

Engineering Leadership's capacity to work through social system complexity existed long before leadership was aimed at working through the exponentially increasing complexity of technology-based systems. Reliance on single domain engineering solutions has given way to the need for systems engineering, engineering managers, and other technology-based interdisciplinary positions to become the integrator, and thus the need for EL. Given the ill-defined discussion on an EL definition and agreed upon competencies in the literature, mapping to the strategic leadership field of study presented by USAWC and ADRP 6-22 provides credibility and structure for an EL framework and can motivate further research and validation.

Conceptual Thinking and Engineering Leadership

"The stone where it strikes the surface of the water, causes circles around it which spread out until they are lost; and in the same manner the air, struck by a voice or a noise, also has a circular motion, so he who is most distant cannot hear it."

---Leonardo da Vinci *[6]*

"Creativity comes into play wherever you have the opportunity to generate new ideas, solutions, or approaches."

---Tom and David Kelley *[7]*

"Innovation distinguishes between a leader and a follower…Sometimes when you innovate, you make mistakes. It is best to admit them quickly, and get on with improving your other innovations… It comes from people meeting in the hallways or calling each other at 10:30 at night with a new idea, or because they realized something that shoots holes in how we've been thinking about a problem. It's the ad hoc meetings of six people called by someone who thinks he has figured out the coolest new thing ever, and who want to know what other people think of his idea."

---Steve Jobs

Conceptual models allow the leader to understand the complexity of the environment on the system. One could easily argue that this is the most critical of the competencies. This competency sets conditions to initially understand the motivation behind the undertaking, define the problem the system is addressing, and finally design, implement and retire the system. Quality performance requires systems thinking, the ability to envision future states, creative thinking and propensity for innovation. Most important of these skills in this competency is the domain of systems thinking as the enabler of the others. Engineering Leadership is strengthened by the leader's iterative reviews of the technology, or system throughout the system life cycle to capture the changes provided interaction with the environment. As the system interacts with the environment, these observations provide the inputs. Updated mental models of how the system should be designed and implemented becomes the output.

Why can we think of “Systems Thinking” as the core of EL conceptual thinking? Systems thinking includes patterns of thought that provide a basis for systematic understanding of real-world systems and challenges. The Leonardo da Vinci quote describes the concept of Connessione, or a ‘recognition and appreciation for the interconnectedness of all things and phenomena [6].’ Systems’ thinking provides a framework in which one can more deliberately analyze the many elements of this volatile, uncertain, complex, and ambiguous (VUCA) environment. It is a way of thinking that we do every day but have rarely codified. One way to unpack systems thinking is by leveraging four simple rules: Distinctions, what something is and what something is not; Systems, everything is a part of a whole; Relationships, every action has a reaction; Perspective, everything has a point of view [8,9]. These four simple rules are a way to bring “order to chaos”. An example of this is observing a flock of birds. Why do flock of birds not collide in flight? Is there a lead bird? Scientists have determined that there is not a lead bird [8,9]. The birds are born to operate under a few simple rules. First, do not run into the other birds. Second, follow the bird in front of you, and finally, keep appropriate spacing. The simple rules can fundamentally assist the Engineering Leader in decomposing the seemingly most difficult of systems.

All VUCA problems are intractable because it is challenging to define what the problems are. The most complex problems require a framework in order to progress towards a solution. The DSRP is one way to categorize what one knows about a situation in order to move towards a viable solution. Understanding the system is a first step in defining the problem.

Hurricane Katrina devastated New Orleans in 2005 placing millions of people in danger. It was not until five days after the storm that the United States Army deployed for response. Lieutenant General Honore’ was placed in charge and quickly assessed the situation. His actions can be analyzed using the DSRP framework. The effects of this storm on infrastructure were unique leading to far worse results than previous storms which created uniquely different governance and law enforcement challenges from the local versus state level; these represented Distinctions. The local government is a part of the federal government, which required LTG Honore’ to synchronize the effort; the System of response needed to be understood. Due to the destruction that had occurred, the lack of food influenced, or caused a direct ‘every man for himself’ environment; understanding these Relationships could guide solutions. Each leader, from the mayor of New Orleans to the senior leaders in the state had a completely different point of view and way in which they thought the situation should be handled; differing Perspectives created friction. Was it simply LTG Honore’s 35 years of experience which brought calm to a crisis? Or, was it his innate ability to use an informal DSRP framework and systems thinking that helped him to save countless lives? Systems thinking became the catalyst for creative and innovative designs in moving the city towards a future safe and stable state.

Envisioning a future state allows EL to guide what the system ought to be, and how it might deliver value throughout its life cycle. Measuring the efficacy of creative and innovative designs requires metrics to ensure the vision is being achieved. With a systems thinking enabled mental model, and a measurable vision for the system, the ability to creatively fail, and wildly innovate has a chance to become ingrained in the culture of the organization. “Acknowledging mistakes is important for moving on…in doing so, you not only sidestep the psychological pitfalls of cover-up, rationalization, and guilt,; you may also find that you enhance your own brand through your honesty, candor, and humility” [7]. The Engineering Leader has the opportunity to shape the culture of the organization through application of the elements of the conceptual thinking competency, and in particular, systems thinking skills. Individual and organizational spirit thrives in a culture where EL is strong, and this leads to excitement in problem solving and achievement of goals for the local, national, and global communities.

Technological Ingenuity and Engineering Leadership

"Whenever you are asked if you can do a job, tell 'em, 'Certainly I can!' Then go get busy and find out how to do it."

---Theodore Roosevelt

"Before you are a leader, success is all about growing yourself. When you become a leader, success is all about growing others."

---Jack Welch

Common to most definitions of leadership in engineering and technology fields is the idea that there is a technical and managerial ability which must exist for EL to be effective. Often, EL shortcomings become the scapegoat for a lack of integration between multiple disciplines, and usually results in system failure. The discipline of Systems Engineering has emerged to work through increasing system complexity in "an interdisciplinary approach to realize successful systems …with an eye on customer needs and required functionality" [10]. Provided that the integration of technologies (existing and emerging) requires engineering acumen, business intelligence, acute science and mathematical foundations and the pulse on emergent technologies, it is proper to examine this leadership competency in the context of the Systems Engineering (SE) discipline.

The nature of Systems Engineering requires a sufficient amount of breadth and depth in multiple engineering disciplines. Figure 2 illustrates how a Systems Engineer must understand the basics of mechanical, electrical, and civil engineering in order to be an effective integrator. Oftentimes, the SE leader began his or her career as a functional engineer or technology expert. The Systems Engineer does not need to be an expert in all traditional engineering disciplines but needs to understand how to rigorously apply a variety of tools to complex problems and possible solutions while simultaneously communicating to primary stakeholders. The Systems Engineer does need to be an expert in Systems Engineering of course!

Expertise is normally acquired from experiences at the undergraduate level. While there is not an abundance of undergraduate programs in Systems Engineering (yet), there are growing amounts of programs focused on Systems Engineering at the graduate level. This would indicate that most Systems Engineers are experts in a particular discipline and have had the opportunity to practice that discipline in their professional lives for some time. Engineering Leadership knowledge, skills and behaviors are often an integrated part of these curriculums formally, or as a part of team events woven throughout.

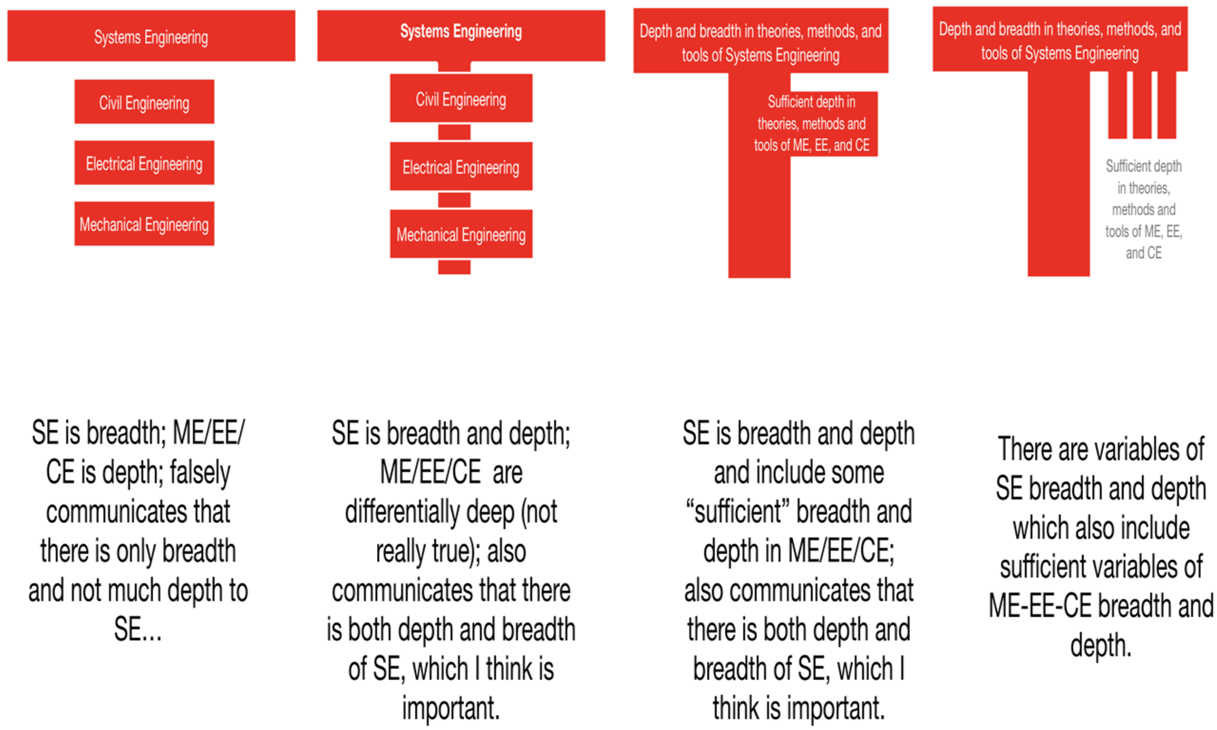

Figure 2: Systems Engineering as an Integrating Discipline of Technologies.

Another way to visualize EL is to look at it through the lens of the SE discipline, and Figure 3 presents that slightly different model from Figure 1. Systems Engineering delivers value at the "Integrative –middle" of engineering disciplines, theories, practice, and tools. As the previous chapter highlighted, there is a "V" relationship where the Systems Engineer is required to have depth and breadth across multiple engineering disciplines meaning the Systems Engineering, or Technological Ingenuity, competence, can be described as T-Shaped [11]. The Systems Engineer can leverage Systems Thinking, or Conceptual Thinking competencies. These two join to become the two of the three Core Competencies of Systems Engineering Leadership.

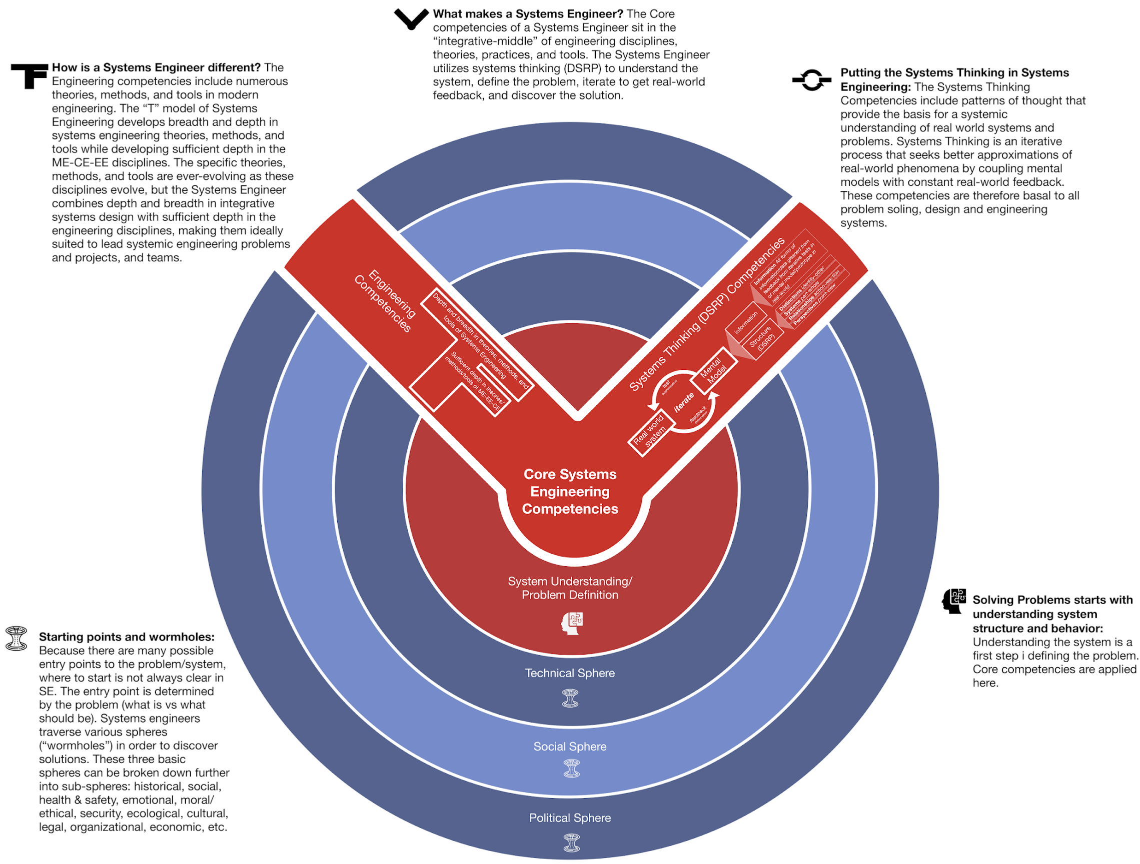

Figure 3: An SE model of Engineering Leadership.

The last leg of the SE leadership model includes developmental leadership opportunities. This one leg might be thought of as representing both the Interpersonal Effectiveness and Ethical Grounding competencies from Figure 1. First, on-the job training is essential to getting the required repetition necessary for specialization [12,13]. Repetition then allows for development and learning to occur which increases tacit knowledge [14,15]. Finally, reflection benefits the Systems Engineering Leader as past experiences and lessons become internalized for application to unfamiliar future situations. With multiple repetitions, the Leadership Competencies only increases [16].

Mental agility and sound judgment enable expertise in one’s domain [5]. The 2017 Hurricane Irma devastation of Puerto Rico mobilized the U.S. Army Corps of Engineers (USACE) along with the U.S. interagency to support over 3.9 million tons of debris removal, over 50 thousand blue roof installations, and the complexity of restoring over 90% of the island’s power grid [17]. While power generation or restoration is not a core technical competency of USACE, Brigadier General Holland, the South Atlantic division commander quickly mobilized 4000 USACE experts in emergency response, technical design, dam experts, and project managers to develop a plan for restoration [18]. The technical competencies were not inherently present for the magnitude of this technical system challenge, yet engineering expertise in recognizing shortcomings and assembling a diverse, interdisciplinary team to tackle this task provides an example of how EL as an integrator of many technical competencies can be powerful in delivering results to the stakeholders. Assembly of these many technical experts to solve a wicked problem requires interpersonal skills to motivate and empower the team!

Interpersonal Effectuality and Engineering Leadership

“Life is a series of experiences, each one of which makes us bigger, even though sometimes it is hard to realize this. For the world was built to develop character, and we must learn that the setbacks and grieves which we endure help us in our marching forward.”

--- Henry Ford

“The best executive is the one who has sense enough to pick good men to do what he wants done, and self-restraint enough to keep from meddling with them while they do it.”

--- Theodore Roosevelt

“The organization is, above all, social. It is people.”

--- Peter Drucker

Interpersonal competence allows for the development of trust internal to an organization as well as externally with clients and stakeholders. Communication in both written and verbal form, are the tools which the Engineering Leader can employ to guide the potential of the organization; without them, the engineering leader has nothing to say [19]! The ability to align the organization, empathize with all stakeholders, empower teams and solve problems become more critical to EL as one moves from entry to enterprise levels, and so investment in the skills which build interpersonal effectiveness should not be taken lightly.

The interpersonal effectiveness of a leader can be thought of through a series of characteristic descriptors. The Engineering Leader is a catalyst for positive action who are effective because they are: Intuitive, Communicative, Passionate, Talented, Creative, Initiating, Responsible, Generous, and Influential [20]. Interpersonal ‘tact’ which allows meaningful interactions relies on acceptance of the team member diversity, displaying self-control and bringing the ‘right’ emotional energy to motivate the team. [5]. The ability to empower, or under-write risk taking by team members, builds trust and can unleash innovative solutions to the most wicked problems presented. Ultimately, effective EL will enable the team, not control it.

Adaptable orientation towards both internal and external stakeholders while impactful, costly, and timely technologies are developed, is required. Losing trust in the realm of public opinion can be equally damaging to an interdisciplinary team’s efforts as internal strife. As technology influences the way we communicate, virtual teaming will increasingly challenge EL requiring interpersonal adjustments. Building consensus, successful negotiation and the capture of system specific details must be met with innovative ways to align efforts across people, processes, policy and technologies.

The workshops at Stanford's Design School, and processes codified at IDEO, show employment of a human-centered approach to solving engineering and technology based challenges. Development of crude and rapid prototyping, interdisciplinary teaming, and empathizing with consumers of those systems [7]. The more diverse the background of the design team, the better! The Engineering Leader of these design teams becomes the catalyst for freedom to create and innovate, yet provides just enough structure to guide the many divergent thoughts back towards solutions which ultimately achieve the stated objective. One key component of EL in this construct is understanding how emergent technologies which exploit the seams of many engineering domains, might create unacceptable currents across the system's environment. Leading the development of new technologies might be possible, but are those solutions acceptable or proper?

Ethical Grounding and Engineering Leadership

"The most important human endeavor is the striving for morality in our actions. Our inner balance and even our very existence depend on it. Only morality in our actions can give beauty and dignity to life."

---Albert Einstein

"Ethics is the activity of man directed to secure the inner perfection of his own personality."

---Albert Schweitzer

'Ethics indicates how a person should behave.' [5]**.** The National Society of Professional Engineers (NSPE) established a code of ethics in 1935, and it remains an integrated part of certifications in the professional engineer (P.E.) domains [21]. Incorporated in the code are assurances to serve the public in the areas of health, safety and welfare, and remain committed to continuous learning. It is however quite possible for Engineering Leaders to not be P.E. certified, and particularly in technology heavy industries where movement into program and project team leadership could occur within the first five or so years within employment.

Societies which have parallel certifications, but not included under the National Council for Engineering Examiners & Surveyors (NCCES) P.E. examinations do exist and incorporate Codes of Ethics. The International Council of Systems Engineering (INCOSE) [22] and American Society for Engineering Management (ASEM) [23] have integrated Codes of Ethics in their bodies of knowledge (Table 1) for each discipline, and incorporate questions in each's professional certifications.

Behavior	Principle	Behavior Characteristics

Respect Others	Treat stakeholders as ends (their own goals) rather than means (to engineer or manager personal goals).	Is respectful of other people's values and decisions. Is empathetic. Is tolerant of opposing viewpoints.
Serve Others	Place stakeholders foremost in engineer or manager plans.	Mentors and empowers subordinates. Builds strong and effective teams. Models good citizenship relative to stakeholders.
Show Justice	Place issues of fairness at the center of decision-making affecting stakeholders.	Treats subordinates equally without favoritism or bias. Actively considers impact on stakeholders in decision-making. Respects the rights of all individuals.
Exhibits manifest honesty	Be sensitive to the feelings and attitudes of affected stakeholders.	Accepts responsibility. Balances openness and candor with monitoring what is appropriate to disclose. Acknowledges and rewards ethical behavior in the organization.
Builds Community	Seeks goals that are compatible with all stakeholders.	Considers the purposes of everyone in a group or team setting. Reaches out beyond personal goals to the wider community. Is sensitive to cultural considerations in a global environment.

Table 1: Code of Ethics Principles for Engineering Managers in ASEM EM Body of Knowledge [24].

Technical, Interpersonal and Conceptual domains of EL should enable ethical behavior. As technologies grow in complexity, a sense of technological optimism can emerge which simply conveys that new systems can be used ‘to accomplish socially desired ends and means’ [19]. Major ethical issues can arise when a rush to implement a new technology without due diligence in study happens. The Engineering Leader must provide the voice of reason in assessing that technology. Defining ethics in these cases requires all three domains to systemically think through possible outcomes of action to develop and implement, and without a measured approach, the results can be catastrophic. ‘Unethical behavior quickly destroys organizational morale and cohesion – it undermines the trust and confidence essential to teamwork and mission accomplishment’ [5].

Growing Engineering Leaders

"Leadership and learning are indispensable to each other."

---John F. Kennedy

"Leaders don't create followers, they create more leaders."

---Tom Peters

"Never tell people how to do things. Tell them what to do and they will surprise you with their ingenuity."

---George S. Patton

Thinking about the future of Engineering Leadership should first begin with the premise that engineer competencies can be developed. Many Leader Development Programs (LDPs) are active in large engineering and technical organizations to include the nation's largest engineering command, the U.S. Army Corps of Engineers [25]. Private Industry value in developing leadership is similar with internal programs and at times outsourced to academia as in Lockheed Martin's Engineering Management Program at the University of Colorado, Boulder. The mission of the Colorado program is to "Prepare individuals who have been working as professional engineers for two to approximately six year for technical management career paths" and Engineering Leadership is one of the many course offerings. Finally, professional societies are increasingly recognizing the need for EL development such as the Society of American Military Engineers (SAME) LDP multi-disciplinary offering [26].

The growing value of EL established, research questions to further the study of Engineering Leadership might include

- What constitutes the best way to assess Engineering Leaders against these competencies?
- When is the best time to begin building capacity in future EL candidates?
- Do EL competencies develop more quickly with on-the-job training versus formal education programs? How do iterative experiences assist in retention?

Engineering Leadership helps to provide vision and alignment for interdisciplinary teams through the four primary competencies. Systems Thinking provides the key to open the gateway for developing knowledge, skills and behaviors for effective EL. Investment in leaders as they evolve into mid and senior levels, is of increasing importance for the ethical innovation of solutions to societal challenges under the VUCA environment.

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