Bernard M. Gordon-MIT Engineering Leadership Program

Capabilities of Effective Engineering Leaders

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Engineers design and build things that fulfill the needs of customers, beneficiaries, and ultimately, society. These activities can only be accomplished by the concerted action of many people who are aligned and rallied by effective leadership. The Bernard M. Gordon-MIT Engineering Leadership Program (GEL) was established to empower MIT students to make the most of their talents and to help them set and achieve personal goals related to these activities. Such goals include making an impact upon, leading, and founding teams and organizations that tackle and solve the types of market and societal problems that can be addressed (at least in part) by technical solutions.

This document serves to guide the curricular and programmatic design of GEL and its associated graduate-level program in engineering leadership (GradEL). Fundamentally, these programs seek to educate and develop the character and abilities of outstanding MIT students as the future leaders of engineering practice and technological development. The programs center on the following definition:

> *Engineering Leadership is the technical leadership of change: the innovative conception, design, and implementation of new products/processes/materials/ molecules/software/systems that meet the needs of customers and society, as enabled by the invention of key technologies and as brought to fruition by teams of people working together.*

We start with the assumption that many students are capable of becoming leaders. At the same time, we observe that with a primary focus on engineering science, existing engineering curricula often do not adequately emphasize the development of engineering leadership[1]. In GEL and GradEL, our educational task is to provide opportunities for all engineering students to further develop the values, character, and capabilities that underpin effective engineering leadership.

Our engineering leadership educational framework encompasses three developmental realms:

- *Personal development* in areas of values, character, and accountability[2];
- *Skills development* in areas that enable action critical to delivering engineering success[3], categorized as: communicating and relating with others, sensemaking, creating and conveying visions, and implementing and delivering upon those visions;
- *Development of technical knowledge and reasoning* in one (or more) engineering domain[4].

In order to address those realms, the curricular scope of the *Capabilities of Effective Engineering Leaders* framework draws from multiple sources. The framework's development was initiated and shaped during a series of consensus-building workshops held at MIT during the winter and spring of 2008. The workshops brought together program stakeholders with diverse perspectives on engineering leadership: alumni, students, faculty, industry leaders, military leaders, community leaders, and educators from other leadership programs at MIT. Following from workshop participants' inputs, the framework's details were further refined and substantiated by two primary

literatures: leadership scholarship[5] and engineering curricular reform efforts[6]. Among leadership scholarship literature, the framework draws from both sub-literatures on personal development[7] and on skills development[8]. Meanwhile, the organization of the framework follows a scheme similar to the MIT Sloan School of Management's Four Capabilities Model[9], as specialized for the case of engineering leadership. Curricular components in the framework are primarily organized into categories reflecting domains of value delivery in engineering and are simultaneously tagged to indicate their association with general areas of leadership development. Over the years since its initial release, this document has undergone several rounds of revision (indicated by the document's version number) based on inputs from the stakeholder community (i.e., students, faculty, industry leaders, etc.).

Our programs operate on the belief that students' capacity for engineering leadership is best developed by linking learning, practice, feedback, and reflection in a timely and systematic way. Program educational elements consequently include:

- Coursework that provides analytical concepts and frameworks for understanding engineering teamwork and leadership;
- Engineering teamwork and leadership practice opportunities;
- Opportunities to gain feedback from peers, faculty, and experienced engineering mentors on lessons-learned from teamwork and leadership activities; also, opportunities to reflect upon and discuss this feedback with peers, faculty, and mentors.

The components of the *Capabilities of Effective Engineering Leaders* are presented below. Many of the components support contemporary published engineering curricula; for these items, bracketed numeric notations (e.g., "[2.4.1]") indicate related topic(s) within the CDIO Engineering Curriculum[10] and parenthetical alphabetic notations (e.g., "(a)") indicate related topic(s) from ABET Accreditation Criteria[11]. The bold numbered headings below indicate the primary engineering leadership capability categories of our framework. Finally, parenthetical labels following each capability indicate its categorization within general areas of leadership development (i.e., *personal*, *interpersonal*, *teamwork*, or *sociotechnical systems* capabilities development).

1. **Core Values, Character, and Accountability:** reflecting upon and developing one's personal values, embracing a growth mindset, and further evolving one's sense of responsibility and accountability in order to build the foundations for character and leadership effectiveness. For effective engineering leaders, these foundations include:

    - *Taking Initiative* – Ability and willingness to assess risk and to take initiative; to create a vision and launch a course of action, including in situations characterized by minimal help, unclear context, or insufficient direction from others. [2.4.1] (Personal)

    - *Making Decisions in the Face of Uncertainty* – Ability and willingness to make decisions based on the information at hand, factoring in risks, uncertainty, and potentially conflicting objectives. [2.4.1] (Personal)

    - *Upholding Responsibility, Sense of Urgency, and Will to Deliver* – Determination to accomplish one's objectives, and those of the team, pragmatically and in the face of constraints, obstacles, and errors by oneself and others. Commitment to the absolute responsibility to persevere and deliver on time, pursuing necessary follow-up. Ability to focus on the tasks at hand with passion, discipline, and intensity. [2.4.2] (Personal)

- *Exercising Resourcefulness, Flexibility, and Resilience* – Ability and willingness to approach problems, tasks, and situations making ingenious use of the resources of the situation and group, and to manage the use of time. A willingness to accept and respond to change, embrace various views, be adaptable, and maintain and take alternative courses of action when necessary. [2.4.2] (Personal)

- *Committing to Ethical Action, Integrity, and Courage* – Adherence to ethical standards and principles. Demonstrating the courage to act ethically and with integrity. Committing to practice in accordance with norms of professional responsibility and one's responsibility to society. [2.5.1](f) (Personal)

- *Exercising Self-Awareness, Self-Reflection, and Self-Improvement* – Awareness of one's own strengths and weaknesses, personal, interpersonal, and professional skills. [2.4.5] Being prepared to continue learning, and proactively planning for one's continuing education, self-improvement, and future career. [2.4.6, 2.5.3, 2.5.4] (i) (Personal)

- *Developing Vision and Intention in Life and Career* – Determining a pathway to one's eventual contribution to and impact on society. Envisioning how engineering plays a role in one's intentions. Commitment to a personal vision and to inspiring others. [2.5.3] (Personal)

- *Fostering Trust, Loyalty, and Team-Building* – Commitment to actions that will instill trust, and to the principle that loyalty to the team yields loyalty to the leader and vision. Working to empower those around you and to make the people around you successful. [2.5.6] (Interpersonal, Teamwork)

- *Embracing Equity, Diversity, and Inclusion* – Commitment to treat others as equals, regardless of status or background, and to embrace diversity in organizations. Being aware of cultural differences in international settings. [2.5.5] (Interpersonal, Teamwork)

2. **Relating:** developing key relationships and networks within and across organizations, including listening to others to understand their views and advocating for your position. For effective engineering leaders, capabilities in this area specialize to:

   - *Inquiring and Dialoguing* – Listening to others with the intention of genuinely understanding their thoughts and feelings. Constructing effective dialogue. Recognizing the ideas of others may be better than yours. Listening to and being willing to learn from everybody. [3.2.7] (Interpersonal)

   - *Developing and Deploying Structured Communications* – Being able to create a strategy and structure to formal communications; presenting information orally, in written form, and graphical form to both engineers and non-engineers in a clear and concise manner. [3.2, 3.3] (g) (Interpersonal)

   - *Negotiating, Compromising, and Managing Conflict*– Appreciating the need to identify potential disagreements, tensions or conflicts, and being able to negotiate to find mutually acceptable solutions. [3.2.8] (Interpersonal)

- *Advocating and Influencing* – The ability to clearly explain one's own point of view or approach, advocate a position, and explain how one reached their interpretation and conclusion. Proactively assessing the extent to which you are understood. Being able to do so to those with and without technical backgrounds, and from different cultures. [3.2.9] (Interpersonal)

- *Building Diverse Connections and Communicating across Cultures* – Appreciating, engaging, and connecting widely with those with different skills, cultures, and experiences. Building a sense of group within direct participants, and building extended networks of those that can help achieve the goals and technical solution. [3.2.10] (Interpersonal)

- *Interacting Constructively; Providing and Receiving Feedback* – Understanding and respecting the unique needs and characteristics of individuals and the group. Recognizing what individuals with different backgrounds can bring to an organization. Coaching, teaching, and providing and receiving evaluation and feedback, while exhibiting elements of gracious professionalism. [3.1] (d) (Interpersonal)

- *Building Relationships and Networks* – Developing and maintaining supportive, productive, and mutually valuable one-on-one relationships and networks (larger sets of relationships) both inside and outside of one's primary organization. (Interpersonal)

- *Managing your Relationship with your Boss* – Creating and maintaining mutual trust, understanding, and effective interdependencies with your immediate supervisor. (Interpersonal)

- *Developing and Empowering Others* – Enabling others to feel ownership and autonomy in their roles and helping them develop the skills needed to carry out their best work outcomes. (Interpersonal, Teamwork)

3. **Sensemaking:** making sense of the world around oneself and coming to understand the context in which the leader is operating. Making mental maps of complex environments, and explaining them to others clearly and straightforwardly. For effective engineering leaders, capabilities in this area specialize to:

    - *Understanding Group and Organizational Cultures* – Understanding the culture of the groups and organizations in which one works, including groups' shared beliefs and widely-held assumptions, as well as the norms for working successfully and bringing forth change. (Teamwork, Sociotechnical systems)

    - *Maintaining Awareness of Societal and Natural Context* – Being aware of and understanding the world's problems, challenges, and opportunities, and the historical and contemporary role of engineering in addressing them. Understanding the natural context and the need for sustainability. Being able to identify opportunities for new (or previously not implemented) engineering solutions and systems to address these needs. [4.1] (j, h) (Sociotechnical Systems)

- *Ascertaining the Needs of Customers or Beneficiaries* – Understanding the specific needs of those who will benefit from the envisioned engineering solution: the customers who will buy it, the users who will use it, the beneficiaries who will directly or indirectly benefit from it. [4.3.1] (Sociotechnical Systems)

- *Exercising Business Context Awareness and Financial Acumen* – Understanding the enterprise in which one works, including the shared beliefs, goals, and strategies of the enterprise. Possessing literacy in broader business concepts and analysis, and in particular, engineering project finance and fundamentals of corporate finance. [4.2] (Sociotechnical Systems)

- *Tracking and Assessing New Technology* – Understanding the emergence and implications of new science and technology. In the context of engineering projects or programs, understanding how new technologies might enable or enhance new solutions and systems. [4.2.6] (Sociotechnical Systems)

- *Exercising Systems Thinking* – Thinking holistically. Possessing an ability to view complexity, focus on critical features, identify inter-relationships and emergent qualities, and create abstractions and models that simplify comprehension. [2.3] (Sociotechnical Systems)

4. **Visioning:** creating purposeful, compelling and transformational images of the future, and identifying what could and should be. For effective engineering leaders, capabilities in this area specialize to:

    - *Creating Motivating Environments* – Building and maintaining a work environment where people are engaged and motivated to deliver high levels of individual and team performance. (Teamwork)

    - *Creating and Communicating a Shared Vision* – Developing and delivering a share team vision that inspires commitment to a shared sense of direction. (Teamwork, Sociotechnical Systems)

    - *Identifying and Defining Issues, Problems, or Paradoxes* – Synthesizing an understanding of situations, inclusive of problems, needs or opportunities. Clarifying the central issues, framing the problem to be solved, or identifying the underlying paradox to be examined. [4.3.1] (Sociotechnical Systems)

    - *Thinking Creatively and Depicting Possibilities* – Understanding how to create new ideas and approaches. Creating and conveying visions for new technical products, systems and new engineering-based enterprises that deliver new capabilities. [2.4.3] (Sociotechnical Systems)

    - *Defining the Solution* – Establishing a vision for the solution and setting achievable goals for performance (including quality), budget, and schedule. This solution vision is guided by the views of the customer and other key stakeholders, reflects the possibilities of technology, considers the full range of alternative approaches, meets regulatory and

political constraints, and considers competitive forces. [4.3.1] (Sociotechnical Systems)

- *Architecting the Solution Concept* – Selecting and architecting the concept for the technical solution, which might be novel or evolutionary. Defining the specifications, interfaces and key elements of the solution so that realization can be effective. [4.3.2, 4.3.3] (Sociotechnical Systems)

5. **Delivering on the Vision:** leading transformation by designing and executing processes and approaches to delivering on the vision; moving from abstraction to implementation. This transformation (e.g., "getting engineering done") is the conversion of inventive ideas and innovative concepts into realized, deliverable solutions. For effective engineering leaders, capabilities in this area specialize to:

- *Forming and Implementing Working Groups and Teams* – Leading the effective formation, launch, development, and adjourning of teams in technology contexts. (Teamwork)

- *Aligning Organizations Toward a Vision* – Strengthening an organization by recruiting key players with complementary and superior skills, tailoring an organization's operating processes and systems, formulating roles and responsibilities, and setting expectations toward achieving project/program/product vision(s). Facilitating group decision-making. Assessing organizational and individual performance. Observing, reflecting, and building upon the leadership qualities of others. Developing approaches to leverage competence outside of one's immediate area in an extended organization. Understanding how to manage organizational change. [4.2.4] In certain cases, creating a new engineering-based entrepreneurial enterprise. [4.2.3] (Sociotechnical Systems)

- *Understanding and Leveraging Power in Organizations* – Evaluating the sources of power in organization, how power is built and used for shared purposes, and how various influence strategies can be adopted to exercise power to get things done in positive ways. (Sociotechnical Systems)

- *Planning and Managing a Project to Completion* – Choosing a development strategy (waterfall, spiral, agile, etc.) and devising primary and alternate plans of action to achieve the goals and deliver on time. Identifying and removing obstacles. Controlling the project to the plan and ensuring its feasibility by balancing cost, schedule, and scope. Identifying when the project is off plan and re-planning appropriately. Managing and apportioning the resources of the team to achieve the desired outcome within the human, time, financial, and technological resources available. Controlling and managing program margins, risk, configuration, and documentation. Understanding the financing and the economics of the project. [4.3.4] (Sociotechnical Systems)

- *Exercising Project/Solution Judgment and Thinking Critically* – Questioning, critically evaluating, and applying judgment to solutions proposed by others. Corroborating inputs. Evaluating evidence and identifying the validity of key assumptions. Applying critical thinking. [2.4.4] Understanding alternatives that may be developed or are being developed by others, including competitors. Taking into account the evolution of existing systems when proposing new systems. (Sociotechnical Systems)

- *Inventing* – Imagining possibilities based on emerging technology or science, and conceiving a practical device, material, process or way of working that enables or enhances a new good or service. Adhering to and leveraging intellectual property regimes. [4.4] (c) (Sociotechnical Systems)

- *Innovating* – Designing and introducing new goods and services to the marketplace. Based on goals and solution concept, identifying, advocating for and amassing the required resources. Designing a solution with the appropriate balance of existing and new technology, reuse and new development, while maintaining flexibility and adaptability. Considering current and future competition. Considering sustainability in the design and implementation. Validating the effectiveness of the outcomes. [4.4] (c) (Sociotechnical Systems)

- *Deploying and Operating Solutions* – Ensuring successful outcomes of engineering endeavors through solution verification (e.g., modeling, simulating, testing), roll-out (e.g., production, deployment), feedback collection (e.g., monitoring), and refinement. Considering quality, variability, and robustness when carrying out implementation plans. Deploying and operating the solution (e.g., product/process/material/molecule/software /system) effectively in a manner such that the needs of the customer and society are repeatably and reliably met. [4.5, 4.6] (Sociotechnical Systems)

6. **Technical Knowledge and Reasoning:** essential to the effective execution of engineering leadership is a deep working knowledge of a technology or discipline. While normally developed in the standard curricular course of study, this knowledge is no less essential for an engineering leader. It includes an ability to understand, decompose and recombine different elements of a technical problem through application of a deep understanding of technical knowledge [1.0] (a, k), engineering reasoning and problem solving [2.1] (e), and the approaches to inquiry and experimentation that may be necessary to develop or refine a new technology needed for a product, process or system. [2.2] (b)

References

[1] For critical reviews of existing engineering curricula and discussion on efforts to introduce leadership development, see:

Crawley, E., Malmqvist, J., Ostlund, S., & Brodeur, D. (2007). *Rethinking engineering education – The CDIO approach*. Berlin, Germany: Springer Science+Business.

Kolmos, A., Hadgraft, R. G., & Holgaard, J. E. (2016). Response strategies for curriculum change in engineering. *International Journal of Technology and Design Education*, *26*(3), 391-411.

Knight, D. B., & Novoselich, B. J. (2017). Curricular and co-curricular influences on undergraduate engineering student leadership. *Journal of Engineering Education*, *106*(1), 44-70.

[2] The values and character development component of our program leverages experiential learning, feedback, and reflection, similar to the learning framework described by Keith et al. (2009), tailored for the non-military university context:

Keith, B. E., Judd, T., Stapleton, J., Stoneham, M., Sweeney, P., & Kruger, K. (2009). *Building capacity to lead: The West Point system for leader development.* West Point, NY: United States Military Academy.

[3] The skills development component of our program centers on building a skill set for effective engineering practitioners and leaders, as presented by ABET (2000) and Crawley et al. (2001). This component of the program aligns with the "skills approach" to leadership, as described by Northouse (2010):

ABET. (2000). "Criteria for Accrediting Engineering Programs: Effective for Evaluations during the 2000-2001 Accreditation Cycle". Available at: http://www.abet.org.

Crawley, E. F. (2001). The CDIO syllabus. *A statement of goals for undergraduate engineering education*. Available at: http://www.orbiter.cdio.org/files/CDIO_Syllabus_Report.pdf.

Northouse. (2010). *Leadership: Theory and Practice.* Thousand Oaks, CA: Sage.

[4] Development of technical knowledge and reasoning is assumed to take place within existing engineering curricula.

[5] For general overviews, see:

Bass, B.M., and Bass, R. (2009). *The Bass handbook of leadership: Theory, research, and managerial applications.* New York, NY: Simon and Schuster.

Northouse. (2010). *Leadership: Theory and Practice.* Thousand Oaks, CA: Sage.

[6] See Reference 1, above.

[7] See Reference 2, above. For overviews of the Growth Mindset and Adult Development theories that underlie this approach, see Heslin and Keating (2017) and Lewis et al. (2005), respectively:

Heslin, P. A., & Keating, L. A. (2017). In learning mode? The role of mindsets in derailing and enabling experiential leadership development. *The Leadership Quarterly*, *28*(3), 367-384.

Lewis, P., Forsythe, G. B., Sweeney, P., Bartone, P. T., & Bullis, C. (2005). Identity development during the college years: Findings from the West Point longitudinal study. *Journal of Col. Stud. Dev.*, *46*(4), 357-373.

[8] See Reference 3, above.

[9] The MIT Sloan 4-Capability Model is described by Ancona et al. (2007):

Ancona, D., Malone, T. W., Orlikowski, W. J., & Senge, P. M. (2007). In praise of the incomplete leader. *Harvard Business Review*, *85*(2).

[11] The CDIO Syllabus Version 1.0 (Crawley, 2001) was the source used during conception and development of this document. Since CDIO v.1.0 was released, an updated version (Version 2.0) has been published within Crawley et al. (2014):

Crawley, E. F. (2001). The CDIO syllabus. *A statement of goals for undergraduate engineering education*. Available at: http://www.orbiter.cdio.org/files/CDIO_Syllabus_Report.pdf.

Crawley, E., Malmqvist, J., Ostlund, S., & Brodeur, D. (2014). *Rethinking engineering education – The CDIO approach, 2nd Ed*. Berlin, Germany: Springer Science+Business.

[12] The ABET 2000-2001 Engineering Criteria (ABET, 2000) was the source used during development of this document. Since ABET (2000), updates have been released by ABET. The second citation, below, provides a link to the latest version:

ABET. (2000). "Criteria for Accrediting Engineering Programs: Effective for Evaluations during the 2000-2001 Accreditation Cycle". Available at: http://www.abet.org.

ABET. (2019). "Accreditation Criteria and Supporting Documents". Accessed at: https://www.abet.org/accreditation/accreditation-criteria/.