Bernard M. Gordon-MIT Engineering Leadership Program

Capabilities of Effective Engineering Leaders

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Engineers design and build things that meet the needs of customers, beneficiaries, and ultimately, society. These activities can only be accomplished by the concerted action of many people aligned and rallied by effective leadership. The Bernard M. Gordon-MIT Engineering Leadership Program (GEL) is dedicated to empowering 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. Fundamentally, GEL seeks to educate and develop the character of outstanding MIT students as the potential future leaders of engineering practice and technological development. Our program centers 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 entering university possess leadership potential. 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 this program, 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, responsibility, and character[2];
- *Skills development* in areas that enable action critical to delivering engineering success[3], categorized as: communicating and relating with others, making sense of context, creating and conveying visions, and implementing and delivering upon 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 categorical organization of the framework leverages a scheme similar to the MIT Sloan School of Management's Four Capabilities Model[9], as specialized for the case of engineering leadership. Following its initial release, this document has further evolved through several subsequent stakeholder engagements with engineering leaders from industry.

Our program operates 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 (both on- and off-campus);
- 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.

In some greater detail, the components of the *Capabilities of Effective Engineering Leaders* are presented below. These components nest within contemporary published engineering curricula: for each item, 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 among ABET Accreditation Criteria[11].

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

   - *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 or direction from others. [2.4.1]

   - *Decision Making 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]

   - *Responsibility, 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]

   - *Resourcefulness and Flexibility* – 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]

- *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)

- *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]

- *Equity and Diversity* – Commitment to treat others as equals, regardless of status or background, and to embrace diversity in organizations. [2.5.5]

- *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)

- *Vision and Intention in Life* – 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]

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]

   - *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)

   - *Negotiation, Compromise, and Conflict Resolution* – Appreciating the need to identify potential disagreements, tensions or conflicts, and being able to negotiate to find mutually acceptable solutions. [3.2.8]

   - *Advocacy* – 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]

   - *Diverse Connections and Grouping* – 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]

- *Constructive Interaction; 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)

3. **Making Sense of Context:** 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:

   - *Awareness of the 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)

   - *Awareness of the Needs of the Customer or Beneficiary* – 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]

   - *Enterprise and Business Context Awareness* – Understanding the goals and culture of the enterprise in which one works; the shared beliefs, goals and strategies of the enterprise; and the norms for working successfully and bringing forth change. Literacy in broader business concepts and analysis, and in particular, engineering project finance. [4.2]

   - *Appreciating 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]

   - *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]

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:

   - *Identifying the Issue, Problem, or Paradox* – 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]

   - *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]

- *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]

- *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]

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:

    - *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]

    - *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. 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]

    - *Exercising Project/Solution Judgment and Critical Reasoning* – 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.

    - *Invention* – 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)

- *Innovation* – 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)

- *Deploying and Operating the Solution* – 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]

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).

[10] 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.

[11] 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/.