

Chapter 1

Beyond Technology: The Holistic Advantage

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ho-lis-tic\hō-ŭlis-tik\ adj.

1: of or relating to holism.

2: relating to or concerned with wholes or with complete systems rather than with the analysis of, treatment of, or dissection into part (Merriam-Webster Online Dictionary)

Today's problems come from yesterday's solutions.

– Peter Senge

We cannot solve the problems of today by thinking the way we thought when we created them.

–Albert Einstein

As engineered technologies become woven into the fabric of our society, engineers ignore the need for integrating valuable, nontechnical skills into their educational paradigm at the profession's peril. The exciting future of engineering is beyond technological labels (e.g., mechanical engineer, electrical engineer, and chemical engineer) where isolated training falls to a more powerful profession of broadly educated “holistic engineers” – engineers who manage, lead, and understand complex, interdisciplinary systems that bring the power of engineering thought to issues spanning and connecting technology, law, public policy, sustainability, the arts, government, and industry. The end of technology as engineering's sole focus allows a future where the engineering profession actively grows and evolves, bringing the very best of science, technology, and innovation to serve the complex challenges of our 21st century lives.

What is the holistic approach to engineering education and practice? In simplest terms, it is a more cross-disciplinary, whole-systems approach to engineering that emphasizes contextualized problem formulation, the ability to lead team-centered

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projects, the skill to communicate across disciplines, and the desire for life-long learning of the engineering craft in a rapidly changing world.

It is an approach that recognizes that engineering's greatest and most immediate challenge for the 21st century is no longer solely how to train capable technical experts – the engineering leadership niche in the manufacturing economy – but how to cultivate professionals able to take on the most complex technological, social, environmental, and economic challenges facing today's societies. Many are unique challenges that did not exist even 20 years ago, ranging from mitigating climate change through smartgrid technologies to securing health records and financial markets in an increasingly inter-connected world.

The holistic approach is a clarion call to today's engineers to reform and reposition their profession, both in educational training and overall practice, to become more systems-focused and globally aware, in the true benefit of a complex, multi-disciplinary, and multi-cultural 21st century. Should we fall short of this important goal, future practitioners risk being pigeonholed as highly-skilled experts who – though brilliant technologists – are without the requisite skills necessary for 21st century leadership in our global, fast-paced information, and innovation economy.

It is a testament to the timeliness, the urgency, and the power of this idea that this book has brought together many of the most distinguished minds in the engineering profession – both educators and practitioners – as contributors to this transformational message: the engineering discipline must become more holistic and collaborative if it is to continue to excel and succeed. Through the diversity and richness of our authors' voices, we hope to present a compelling, varied, and globally-informed argument for not only the immediate reform of traditional engineering curricula, but for a full embrace by practitioners of more systems-focused, interdisciplinary, and holistic approach to engineering projects.

We begin with education.

The term “holistic engineering” was likely first coined by University of Pennsylvania Professor Joseph Bordogna, former Deputy Director of the National Science Foundation and former IEEE President, as he was describing a more cross-disciplinary, whole-systems approach to engineering education. In 2007, a *Chronicle of Higher Education* essay entitled *Holistic Engineering* (reprinted as Chapter 2), by *Domenico Grasso*, an editor of this book and then-Dean of the University of Vermont College of Engineering and Mathematical Sciences, with co-author *David Martinelli*, Professor of Engineering at the University of West Virginia, laid out an overview of the core reasons so many in engineering leadership, from cutting-edge universities to multinational corporations, have been calling for change in the traditional approach to engineering education and practice. This essay also helps to lay the foundation for the many contributions found in this book. Examples in the essay illustrate the authors' clear theme: the future of the engineering profession will be most competitive for those adopting holistic approaches to their practice, marrying quantitative expertise with communication and teamwork skills, and creative thought to envision entirely new solutions than might not have been allowed under traditional, solely technologically-focused engineering approaches.

Following this opening and in a similar vein, the next essay, *Engineering for a Changing World: A Roadmap to the Future of American Engineering Practice, Research, and Education*, is penned by one of the foremost leaders and advocates for US engineering reform *James Duderstadt*. The President Emeritus of the University of Michigan and member of the National Academy of Engineering (NAE) Duderstadt is blunt and compelling with his arguments. The United States faces the very real prospect of losing its engineering dominance and competence, argues Duderstadt, in an era in which technological innovation is key to economic competitiveness, national security, and social well-being. Despite clear statistics showing the importance of engineering to a competitive and strong economy, studies show that US engineering professionals are still held in relatively low esteem in comparison to other professional disciplines and, sadly, this perception has translated into an inadequate national investment in engineering education as well as overall science and engineering research, ultimately rendering the field less attractive to the brightest young minds. Duderstadt's essay sounds the alarm for immediate change, and also presents a bold plan for transformative actions and investments – in universities, government, and the engineering profession itself – that, he reasons, will help to avert a national crisis.

Many claim that a deterioration of quantitative K-12 education is a primary cause of the challenges faced by engineering educators. In Chapter 4, *K-12 Engineering: The Missing Core Discipline*, *Iannous Miaoulis*, President and Director of the Museum of Science in Boston, home to the National Center for Technological Literacy calls for holistic engineering thought to reach even the youngest of our potential future engineering leaders. We live in a world, Miaoulis writes, created largely by human hands and thought – an engineered world. Yet as American youth navigate the classical K-12 curriculum of reading, writing, mathematics, biology, physics, and chemistry, they rarely learn about engineering as a globally transformative profession or its continuous impact on our daily lives. How can this be? Miaoulis explores both the etiology and remedies for this “missing core discipline.” Acknowledging that bringing engineering ideas into the K-12 curriculum will not be easy, Dr. Miaoulis makes a compelling argument that an attempt to do so will help create a far more technologically literate populace.

Engineering education and practice occupies a complex space. On the one hand, it is a professional field of creative practice common to the liberal arts – architecture, painting, dance; and on the other hand, it is a field in which research is inspired by use. However, over the years a tension has developed between traditional liberal arts and engineering. In her essay, *Liberal Arts and Engineering*, *Catherine Koshland*, Vice Provost for Academic Planning and Facilities and Wood-Calvert Professor in Engineering at the University of California at Berkeley, examines engineering in the context of liberal arts colleges. The application of science through technology, she notes, can improve the welfare of many throughout society; but such technological interventions will not succeed if they are applied in the absence of cultural or social understanding, hence the need for a broader, more liberal engineering education.

Following in the liberal arts context is an essay by *Carol Christ*, President of Smith College – the first women's college, and one of the few liberal arts colleges

in the United States to develop an undergraduate engineering program. In *What is Happening in Liberal Education?* Christ begins with an historical overview of the liberal arts curriculum and its own significant transformations over time. Christ specifically describes seven current key developments in the liberal arts that can be seen to parallel the challenges facing engineering today, including a movement away from subject matter to intellectual capacities as an organizing concept, interdisciplinarity, internationalization, an increasing emphasis on training for citizenship, environmental education, an increased focus on undergraduate research, and an increased focus on project-based learning. Christ's essay firmly establishes that, given the call to transform engineering education to a more holistic, 21st century approach, it is clear that engineering should be considered a liberal art.

A recurring theme for those interested in engineering education reform is that the complex challenges of the coming century will demand more creative, innovative, and holistic solutions – solutions that will require a new paradigm for pre-professional undergraduate preparation in our engineers. In their essay, *Holistic Engineering and Education Reform*, Domenico Grasso and Joseph Helble, Deans of the College of Engineering and Mathematical Sciences at the University of Vermont and the Thayer School of Engineering at Dartmouth College, respectively, summarize several programs with innovative engineering curricula designed to meet the challenge. Their essay explores the motivation to pursue engineering careers and calls into question the often cited and much-touted historical impetus of the 1950s and 1960 s, i.e., “Sputnik.” They note that many engineers briefly or never practice in the field in which they receive their training and they point to the need for life-long learning. Grasso and Helble suggest that a first step in moving toward a curriculum that can better educate holistic engineers might be to work toward true multidisciplinary at both ends of the undergraduate experience. By structuring a first year design course that brings together students of varied interests and backgrounds, the profession of engineering can be better contextualized within a societal framework in the students' earliest college experience, inspiring them to seek creative and impactful solutions as a core part of their engineering education. They also recommend that a unified senior design course be created to complement this first-year course – one that is truly interdisciplinary and involves engineering students of all disciplines working together, preferably in coordination with real-world business and marketing interests. Both, taken together, are an exciting first step in better preparing our engineering students to creatively design the integrated and holistic engineering solutions that will best serve society's complex needs.

The definition of holistic is that it is “relating to or concerned with wholes or with complete systems rather than with the analysis of, treatment of, or dissection into part.” For engineering education this aligns ideally, of course, with the future of systems engineering. Priscilla Guthrie, the Chief Information Officer for the National Intelligence Community, challenges engineering educators with her chapter, entitled *Beyond Systems Engineering – Educational Approaches for the 21st Century*, where she posits that undergraduate engineering education has essentially walked away from the challenge of educating systems engineers, instead offering students

an outdated, but growing, list of the “by-discipline” (electrical, mechanical, civil, environmental, and chemical) basics throughout their engineering program. Guthrie argues that this educational paradigm is neither sufficient, nor helpful, to modern engineering students or their future professions and identifies selected educational outcomes and reforms – including more holistic approaches to educating systems engineers – she believes should be pursued to better prepare student for modern engineering practice and study.

As US engineering leaders struggle with critical transformation of their engineering educational system, so do those on the international front. In the next two chapters, engineering education reform is explored by both *Hector Gallegos*, President of the Peruvian College of Engineering and Professor of the Universidad Nacional de Ingeniería, Pontificia Universidad Católica in Perú, and *Pan Yunhe*, President of the Chinese Academy of Engineering and President of Zhejiang University in China.

In the first of these essays, *The Education of an Engineer in a Holistic Age: A Latin American Perspective*, Professor Gallegos focuses his critique of the current engineering curriculum on the status quo he sees pervasive, and persistent, in Latin American engineering programs. Potential is being lost, he argues, to build the lasting infrastructure for engineering innovation and growth throughout Latin America. Gallegos goes further, with a detailed curriculum proposal for 21st century engineers including mathematics, basic science, and engineering science integrated seamlessly with core courses in culture, history, and importantly, design. He provides examples of how to prompt engineering students in this new, more integrative, reflective curriculum, requiring them to move away from purely technological and/or solo interests and work collaboratively across disciplines. He urges them to continuously ask questions, not once but multiple times, of themselves and their team as to the necessity, safety, benefit, and importance of an engineering project to society and the environment. Gallegos ends his essay with a special plea to engineering faculty – both in Latin America and globally – to recognize the importance of a more holistic, enlightened engineering education and to join in this much needed transformation, for future of both engineering and society.

The second international contribution, *On the Cultivation of Innovative Engineering Talent*, is a unique contribution from distinguished engineering colleagues in China. Complementing the ideas of Gallegos and contributors from throughout the United States, Yunhe argues that a more holistic approach to engineering – specifically with a focus of integrating more design, communication skills, and multidisciplinary thinking into the engineering curriculum – is of paramount importance to the cultivation of engineering excellence. Yunhe also gives new insight into how he expects China may accelerate the cultivation of highly talented 21st century engineers, with examples of programs and investments from his own Zhejiang University, where there is active pursuit and aggressive selection of the best and brightest students, coupled with their enrollment in advanced, intensive engineering and innovation programs that are “foundation oriented, design oriented, and creation oriented.” In his essay, Yunhe expounds upon the importance of collaborative exchanges with industry, the need for international exchange of ideas,

and the importance of a multidisciplinary perspective and innovative personality in the best 21st century engineer. With some aspects of the essay likely unique to the Chinese educational infrastructure and existing coordination with government and industry, the larger theme of the essay aligns with leading authors throughout this compilation: advocacy for an investment – as soon as possible – in a future of more holistic, globally-aware, and multidisciplinary approach to engineering.

A significant component of a holistic education is better understanding the world around us. This is especially true for engineers practicing in a global economy. In Chapter 11, *International Education and Holistic Thinking for Engineers*, Dennis Berkey, President of Worcester Polytechnic Institute (WPI), brings yet another critical yet under-utilized opportunity for engineering education reform to the table: the “purposeful” study abroad experience. While there has been a dramatic rise in popularity of study abroad programs for college-age students in the past 30 years, Berkey writes, less than 3% of all US study abroad students are engineering majors. At the same time, the inter-connectedness of today’s economy – and the importance of technology in international commerce – suggests that an engineering education should require students to have a sense of the world beyond their campus or state. Berkey describes the development of a “purposeful” international experience for engineers that not only exposes students to new cultures, but also requires that the time spent abroad involve team-building and collaborative learning, interdisciplinary exposure, and new ways of communicating. Berkey argues that, in this way, a study abroad experience for engineers serves as the ideal platform for gaining holistic “21st century skills” and excelling in global innovation.

Engineers, with their technological expertise positioned ideally at the fertile intersection of both applied science and commercial business, are the prototypic creators of value in global economy. The next chapter, *Engineering Value Propositions: Professional and Personal Needs*, is a contribution from Gary Wnek and Suzette Williamson, both of The Institute for Management and Engineering (TiME) at Case Western Reserve University. The essay focuses on the rapidly changing, global innovation economy that requires a concomitant change in the engineering profession. If it is to maintain its positioning as a value creator, engineering must embrace a more integrated, interdisciplinary, and whole-systems approach. Referred to as the “Holistic Engineer” and “21st Century Engineer” in various complementary chapters in this collection, Wnek and Williamson propose yet another term for this new engineer, the “New Economy Engineer.” They further use a simple metaphor for metabolic energy to engagingly suggest that it is “ATP” – or analysis, translation, and perception – that “fuels” the New Economy Engineer. Their hypothesis is that developing ATP in our undergraduate engineering students will be key to their competitive future as professionals.

David Goldberg is the Jerry S. Dubrovlny Distinguished Professor of Entrepreneurial Engineering at the University of Illinois at Urbana-Champaign, founder of the Illinois Genetic Algorithms Laboratory and author of “The Entrepreneurial Engineer.” As an engineering educator fascinated by innovation and entrepreneurship, Goldberg wonders why, when engineering faculty colleagues talk about “the basics” of engineering education, he too often hears them refer solely to

mathematics, science, and the engineering science disciplines. To be certain, mathematics, science, and engineering science are important, but are they really the most basic subjects critical to being an engineer? In his chapter entitled *The Missing Basics & Other Philosophical Reflections for the Transformation of Engineering Education*, Goldberg argues that this persistent definition of “the basics” is sadly inconsistent with the true needs of modern engineering practice and innovative ability. Goldberg further suggests seven critical thinking skills that should, he argues, become the new fundamentals of a 21st century, holistic undergraduate engineering education: asking questions, labeling technology and design challenges, modeling problems qualitatively, decomposing design problems, gathering data, visualizing solutions and generating ideas, and communicating solutions in written and oral form. He suggests that the failure of engineering education to address the missing basics is substantial – and that engineering education needs to change its thoughts, language, and practices to make the missing basics more central to the engineering canon.

It is in the context of this global “call to action” for education reform that *Domenico Grasso, Melody Brown Burkins, Joseph Helble, and David Martinelli*, furthers the compelling argument for 21st century engineering education transformation. *Dispelling the Myths of Holistic Engineering* was written as a response to skeptics in the traditional engineering education community who argue that any change to the status quo in curriculum and practice imperils the profession, the essay directly confronts five myths oft cited as reasons engineers, and engineering educators, should not alter their ways. Written at the request of the editor of *PE Magazine* and appeared in the August 2008 issue, this essay also buttresses arguments made by David Goldberg in exposing such educational myths not only as unhelpful to the profession, but seriously flawed, unsubstantiated, and illogical. The authors note that engineering educators who cling to 1950s models of teaching – e.g., adding more and more technologically specific classes to an already overwhelming engineering course load – are not preparing their students to succeed in today’s rapidly evolving, information economy. Instead, the authors note, these educators stand in the way of a more holistic, and competitive, education paradigm for their students’ best future, where young minds are trained in the fundamentals of engineering thought – how to “think like engineers” – and gain professional skill that will last their lifetime.

Just as the first chapters of this collection have focused on the potential for a transformation in engineering education to meet 21st century challenges, the next series of essays focus on new trends in engineering practice that are essential for corporate leadership.

These begin with an excellent analysis of the profession by *Wanda Austin*, President of the Aerospace Corporation, with her colleagues *Marilee Wheaton* (also an adjunct faculty member at the University of Southern California), *Charles Tang*, and *Mark Goodman*. The essay, *The Practice of Systems Engineering and Technological Leadership*, opens with the observation that failures in large-scale engineering projects, many resulting in multibillion-dollar cost overruns, are often blamed on the “complexity” of the project. Austin and her co-authors deconstruct this argument, offering a clear perspective on why “technical leadership” is so

critical to the success of complex engineering projects, and how the practice of effective systems engineering enhances and enables that leadership. Using a diversity of examples to make their case, many from the aerospace industry, the authors aver that a holistic worldview in engineering is required as our knowledge-driven society increases its reliance on technology in order to enhance our daily quality of life. They further lobby strongly for the value of more holistic, systems engineering approaches to successfully tackle the increasing complexity of engineering projects and ensure outcomes beneficial to 21st century society.

The power of a more holistic, systems engineering approach to complexity – and the introduction of complex systems as an emerging and critical focus for the 21st century engineering enterprise – is the theme of the next essay from the President and CEO of the MITRE Corporation, *Alfred Grasso*, and his colleagues *Lou Metzger*, *Rich Byrne*, *Steve Huffman*, *John Kreger*, and *Marie Francesca*. In Chapter 16, *Holistic Systems Integration*, the authors explain that today's engineers – no matter their specialty – can no longer expect to design and build single-purpose systems that operate flawlessly in isolation, but must recognize that their work will be part of a larger, heterogeneous system, with each component built for different businesses and users, that is constantly sharing information and interacting. Similar to Austin et al., the MITRE team suggests that to design systems that can perform as components of a large-scale, complex enterprise, engineers must expand the definition of the system and contextualize it within the enterprise in which it will function. Engineered systems must interoperate with, respond to, and – adopting Darwinian language – rapidly “co-evolve” with the real-time changes in technical, social, economic, and environmental surroundings. This increasingly dynamic nature of 21st century engineering systems development – and the associated unpredictability of those systems as they become more and more complex – poses significant challenges to traditional engineers. However, this evolution also offers vast opportunities for creativity and innovation in design to the next generation of more holistically-trained, systems-focused engineering professionals who not only understand complexity, but embrace complex systems as a fascinating emerging market for the profession. [see Chapter 17]

The fact that IBM Corporation has been a leader in and trendsetter for emerging global markets in engineering is indisputable. In the 1970s, IBM urged universities in the United States and overseas to invest in the computer science major, recognizing the potential of information technology and information systems as the worldwide growth area of the future needing a talented workforce and career professionals. Since that time, IT has become an integral, if not a dominating, force in international commerce and innovation. In their essay for this collection, *Collaborative Innovation and Service Systems: Implications for Institutions and Disciplines*, National Academy of Engineering member and IBM Fellow and former Executive Vice President of Innovation and Technology, *Nicholas Donofrio*, with colleagues *Calline Sanchez*, Director of Systems Storage Development, and *James Spohrer*, Director of Global University Programs, advocate for the idea that system services are the next, exponential global growth area, calling for the

immediate development of a “Services Science” that is grounded in a more holistic approach to engineering education. Their essay argues that investment in new global markets – all of which are expected to be largely multidisciplinary, collaborative, and rich with complexity – will require a workforce of professionals with the ability to understand complex systems and the services they bring to dynamic markets. They proffer that wherever people (and their determination of value) play an important role in the dynamics of complex systems, as in industrial and system engineering, financial engineering, software engineering, we will see an integrative force, working against specialization and toward more collaboration and cross-disciplinary skill sets. Service science and holistic engineering are both integrative disciplines – and while 21st century engineering professionals will always need expertise in a traditional or fundamental discipline, they will also need communication skills across a wide range of other disciplines and an ability to manage complex projects, people, and cultures. Fundamentally, the cultivation of more holistic engineers will serve to ensure a high-quality workforce and professionals leading collaborative innovation and services science programs.

The final chapter, *Technology and Policy*, of the book focuses on the knowledge, and study, of policy as one of the most powerful drivers of our global economy that will benefit from more holistic approaches to engineering education and practice. *M. Granger Morgan*, Head of Engineering and Public Policy at Carnegie Mellon University and Member of the National Academy of Sciences, notes that, in the 1960s and 1970s, and on some campuses even today, engineering education programs of the post-war period produced an environment in which many faculty belittled any activity – such as policy studies – not laden with partial differential equations. Today, however, many science and engineering educators are beginning to recognize the importance of preparing students with technical backgrounds who can address policy problems in which the technical details matter, both in terms of the way in which problems are framed and the analytical tools that are employed, but are not always paramount. This is part of increasingly complex engineering challenges, which marry societal, economic, environmental, media-related, and cultural differences around the world into beneficial solutions. Furthermore, techniques such as decision analysis, the systematic characterization and analysis of uncertainty, and methods in quantitative risk analysis, which were pioneered in engineering best serve the policy sector when holistic perspectives can be accommodated. Morgan is optimistic that, today, thousands of graduates of programs in technology and policy are beginning to approach their work in a more holistic way than their more conventionally educated engineering colleagues. For that, he suggests, they may well be the leaders of our global, technological future.

The book we have assembled, taken in its entirety, has many voices but one clear message: the current state of engineering education and practice which is designed largely for a manufacturing economy in the previous century must change – and change quickly – to meet the complex, global challenges of dynamic, 21st century information and innovation economy. In this new environment, investment in 20th century status quo engineering, adding more and more technological coursework

to already overloaded engineering degree and shunning the complexity of modern engineering challenges, becomes a sadly Sisyphean task that is not only endless and ineffective, but has little benefit to the future of the engineering profession.

We have largely given the name “Holistic Engineer” and “Holistic Advantage” to this new thinking and investment for 21st century engineering and practice. Yet, by any other name – be it the 21st Century Engineer, Service Science Engineer, Systems Engineer, Global Engineer, New Economy Engineer, and Renaissance Engineer – the future of engineering is about reform.

It is also about competitiveness, life-long learning, and a true bridging of the engineering, scientific, and traditional liberal arts worlds that for too long have operated independently, even resentfully and without respect for each others’ strengths. C.P. Snow once bemoaned the “Two Cultures” in his now-famous 1959 Rede lecture at the University of Cambridge (UK), believing the “science vs. liberal arts” dichotomies created by disciplines did little to benefit society. Instead, the division engendered mistrust and miscommunication, with both the engineering and liberal arts communities missing great opportunities to share strengths toward new discovery and enlightenment. We agree. The holistic approach presented in the essays throughout this book is not only about a long-overdue shift in outdated engineering education paradigms, but about positioning the engineering profession to reach its 21st century potential as a most competitive, cost-effective, and attractive profession in the global marketplace as well as a most respected, and sought-after, degree throughout academia.

I can’t understand why people are frightened of new ideas. I’m frightened of the old ones.

– *John Cage*



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