Winter 2018

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The
BRIDGE

NATIONAL ACADEMY OF ENGINEERING

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Mission Statement of *The Bridge*

The Bridge publishes articles on engineering research, education, and practice; science and technology policy; and the interface between engineering and technology and society. The intent is to stimulate debate and dialogue both among members of the National Academy of Engineering (NAE) and in the broader community of policymakers, educators, business leaders, and other interested individuals. *The Bridge* relies on its editor in chief, NAE members, and staff to identify potential issue topics and guest editors. Invited guest editors, who have expertise in a given issue's theme, are asked to select authors and topics and to enlist colleagues to assess (in aggregate) articles for publication. The quarterly has a distribution of about 7,000, including NAE members, members of Congress, libraries, universities, and interested individuals. Issues are available at *www.nae.edu/Publications/Bridge.aspx*.

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Editor's Note

Ronald Latanision (NAE) is a senior fellow with Exponent, Inc.

New Perspectives on Engineering

Each year the winter issue of *The Bridge* focuses on the US symposium of the NAE's exciting Frontiers of Engineering (FOE) program. As **Jennifer West**, chair of the Organizing Committee, observes in her guest editor's note, this unique program provides an opportunity "to facilitate cross-disciplinary exchange and promote the transfer of new techniques and approaches across fields in order to sustain and build US innovative capacity."

Also in this issue, I am pleased to present three contributions that I believe will be of interest to our readers.

Guru Madhavan and Charles Phelps (NAM) write about human factors of democracy, looking at one of the most cherished attributes of a civil society: voting. They consider underlying human factors in order to better understand the meaningfulness of voting methods from a user's standpoint: "The use of engineering design tools can not only enable more expressive public opinion for important decisions but also lead the way toward scientifically informed choice systems, thereby improving public policy decisions and, ultimately, democracy."

Technology opens new doors every day. Yet it seems to me that we have not paid nearly enough attention to the social science/human factors dimension in the evolution of engineering systems. Meera Sampath and Pramod Khargonekar focus on the development of automation and introduce the concept of socially responsible automation (SRA). They recognize that technical progress is part of our culture and that the key is to implement measures that enable technologists, business leaders, and the workforce to benefit from these transformative technologies. To that end they provide a systematic, structured way to frame choices, assign priorities, and design robust strategies. To illustrate, they discuss the role of artificial intelligence with the goal that SRA will inspire and help shape a future where automation and AI work for all.

The intellectual infrastructure represented by the engineering research and education programs in our universities is one of this nation's greatest assets. The leadership of these programs is crucial and the selection of the academic leader, the dean, is therefore a high priority. Richard Skinner describes the paths to the deanship in US engineering programs. In the context of the continuing and essential effort to diversify both the student population and the faculty, he focuses his study on the characteristics of signatories to a recent ASEE diversity commitment, the goal of which is "to provide increased opportunity to pursue meaningful engineering careers to women and other underrepresented demographic groups."

Extending our series of interviews with engineers who add to our culture in a multiplicity of ways, the featured interviewee in this issue is pro golfer Maverick McNealy, who received his BS in management science and engineering from Stanford in 2017. He explains how he brings an engineering perspective to his game and equipment.

Looking ahead, I'm pleased to announce that in the spring 2019 issue we will introduce a new column, EES Interface, that will consider the ethical dimensions of topics treated in each issue. The column will be managed by the new director of the NAE Center for Engineering Ethics and Society (CEES), Rosalyn Berne (introduced in the fall issue, p. 84). Engineering systems include technical, economic, social, and public safety risks and considerations that should be part of all engineers' decision making. With this column we will address these considerations. We welcome and look forward to working with Ros.

The next issue will focus on technologies in support of aging. With the growth of aging populations in this and many developed countries, the emergence of increasingly sophisticated technologies and users, and the confluence of the desire for independence and technologies available to facilitate and enhance both independence and quality of life, the topic is compelling and relevant.

As always, I welcome your comments and feedback at rlatanision@exponent.com. I hope this issue might stimulate the kind of conversation that is high on my list of priorities for *The Bridge*.

Guest Editor's Note

Jennifer West (NAE) is the Fitzpatrick Family University Professor of Engineering in the Department of Biomedical Engineering at Duke University.

Engineering at the Cutting Edge

The US Frontiers of Engineering Symposium, held September 5–7 at MIT Lincoln Laboratory, brought together an incredibly diverse group of talented young engineers representing the best and brightest from academia, industry, government, and nonprofit sectors across all engineering disciplines. This unique symposium provided attendees an opportunity both to learn about some of the most cutting-edge and impactful engineering developments and to network and enjoy intellectual discussions across traditional boundaries in engineering. The session topics were

- Quantum Computers
- The Role of Engineering in the Face of Conflict and Disaster
- Resilient and Reliable Infrastructure
- Theranostics.

The meeting was introduced by **C. D. Mote, Jr.**, NAE president, and by **Eric Evans**, director of MIT Lincoln Laboratory.

The first session, on quantum computing, was chaired by Grace Metcalfe from the Air Force Office of Scientific Research. Sara Gamble (Army Research Office) gave a very educational overview in her talk "Quantum Computing – An Introduction to What It Is, Why We Want It, and How We're Trying to Get It." Many in the audience were unsure what quantum computing really is, and this talk provided a very clear introduction. It was followed by presentations on quantum algorithms by Shelby Kimmel (Middlebury College) and on logical quantum computing by Sarah Sheldon (IBM T.J. Watson Research Center). The session ended with a stimulating talk by Norman Yao (University of California, Berkeley) about three experimental platforms for quantum simulation: ultracold atomic systems, polar molecules, and superconducting quantum bits (qubits).

During a poster session after lunch participants shared and discussed their research, and continued these discussions throughout the meeting. Sohi Rastegar from the National Science Foundation then gave a short talk, "Where Are the Emerging Frontiers of Research and Innovation?"

The second session, The Role of Engineering in the Face of Conflict and Disaster, was chaired by Francesca D'Arcangelo (MIT Lincoln Laboratory) and Mira Olson (Drexel University). The first two presentations were Wednesday afternoon, and the session continued with two more talks on Thursday morning. Julia Moline (FEMA) discussed the use of mapping technologies to more rapidly assess damage after Hurricane Harvey (2017). Darshan Karwat (Arizona State University) gave a thought-provoking talk, "Engineering for the People: Putting Peace, Social Justice, and Environmental Protection at the Heart of All Engineering," about how to inspire engineering students. Willow Brugh (Truss) explained the need to integrate formal and informal disaster response teams. Closing the session, Marissa Jablonski (USAID) described USAID efforts in disaster relief.

On Wednesday evening, the participants enjoyed a fascinating lecture by Grant Stokes, head of Space Systems and Technology Division at MIT Lincoln Laboratory. We were left with a bit of fear about near-Earth asteroids!

The third session, Resilient and Reliable Infrastructure, was chaired by Iris Tien (Georgia Institute of Technology) and Julie Pietrzak (Enovate Engineering). Josh Vertalka (RS21) opened with a talk entitled "Communicating Advanced Infrastructure Resiliency Analytics to Diverse Groups of Stakeholders." Next, Robert Hanson (Department of Homeland Security) described his work, "Identifying Infrastructure Dependencies and Interdependencies." Firas Saleh (Jupiter) concluded the session with "Climate Change and Infrastructure

Resilience," leaving us with provocative images and a lot to ponder.

On Thursday afternoon, the group was treated to a fantastic set of tours at MIT Lincoln Lab, with opportunities to see the Flight Test Facility and the Antenna Test Range at Hanscom Air Force Base, the Space Surveillance Complex, the Air Traffic Control Decision Support Facility, and the Micro Electronics Laboratory.

The final session, Theranostics, took place Friday morning and was chaired by Rebekah Drezek (Rice University) and Darrell Irvine (MIT). Andrew Tsourkas (University of Pennsylvania) gave an excellent introduction to the issues associated with combining diagnostics and therapeutics in a single platform. Ester Kwon (University of California, San Diego) presented her work on "Synthetic Biomarkers for Cancer Detection and Diagnosis." And Evan Scott (Northwestern University) described the use of nanobiomaterials to improve vaccination and the treatment of inflammatory diseases.

The next US Frontiers of Engineering Symposium will be held September 25–27, 2019, hosted by Boeing in North Charleston, South Carolina. I encourage you to nominate outstanding young engineers to participate so that we can continue to facilitate cross-disciplinary exchange and promote the transfer of new techniques and approaches across fields in order to sustain and build US innovative capacity.

Quantum computing may revolutionize industries from pharmaceuticals to materials research and finance with a different way to process information using quantum mechanical systems.

Quantum Computing with Noisy Qubits

Sarah Sheldon

Sarah Sheldon is a research staff member in quantum computing at the IBM T.J. Watson Research Center.

Quantum computing has the potential to revolutionize a wide array of industries, from pharmaceuticals and materials research to finance and logistics, by offering a fundamentally different way of processing information using quantum mechanical systems. The promise of quantum computing lies in its ability to store and process information in quantum bits (qubits), which are notoriously fragile (i.e., they can lose their information easily through interactions with their environment). It is also exceedingly difficult to simultaneously isolate a quantum system from noise and to control it precisely.

Introduction

The idea of quantum computing first arose in the context of quantum simulation. Richard Feynman (1982) proposed that to properly simulate quantum systems, one must use a quantum computer, but quantum computing was considered impractical because of the inability to control qubits without errors.

Quantum computers are made up of individual qubits that are coupled to noisy environments (stray electromagnetic fields or material defects that can exchange energy with qubits). Unlike classical computers, they cannot rely on redundancy to prevent errors. Additionally, the state of a qubit can be a linear superposition of $|0\rangle$ and $|1\rangle$ and so any error correction must preserve the qubit's additional phase information (Gottesman 2009).

The field of quantum computing was advanced by discoveries of quantum error correction (QEC) codes in the 1990s (Laflamme et al. 1996; Shor 1995; Steane 1996). These codes, along with others since developed, work by encoding a logical qubit (a fault-tolerant qubit that is fully error corrected) into the space of many physical qubits (the underlying noisy physical systems). Shor's error correction code, also called the repetition code, works by encoding a logical qubit into nine physical qubits using the following definitions of the logical states:

$$|0_L\rangle = (|000\rangle + |111\rangle) \otimes (|000\rangle + |111\rangle) \otimes (|000\rangle + |111\rangle)$$
$$|1_L\rangle = (|000\rangle - |111\rangle) \otimes (|000\rangle - |111\rangle) \otimes (|000\rangle - |111\rangle)$$

A bit flip can then be detected and corrected based on "majority voting," i.e., the state $|100\rangle + |011\rangle$ with an error on the leftmost qubit is returned to $|000\rangle + |111\rangle$ Similarly, phase flips are detected based on sign changes between the groupings of three qubits.

Surface Code

Quantum error correction codes include stabilizer codes, whose many variants each have different requirements for numbers of qubits and error thresholds.

One typical example of a stabilizer code is the surface code (Bravyi and Kitaev 1998), a topological code defined on a 2D lattice of qubits that is currently popular for those designing hardware around a QEC code architecture. The advantage of the surface code is that it has a relatively high error threshold (the level of errors that can be corrected) and requires only nearest neighbor connectivity.

Recent experiments have demonstrated various building blocks of the surface code architecture (Corcoles et al. 2015; Kelly et al. 2015; Riste et al. 2015; Takita et al. 2016). The number of physical qubits needed to build a logical qubit depends on the type of errors and the error rates present on the physical level. In Shor's QEC code, the logical qubit consists of nine physical qubits (one data qubit and eight ancillae) and corrects for both phase and bit flip errors on the data qubit. Errors can also occur in the ancilla qubits as well as the data qubit; encoding into a larger number of physical qubits is necessary to correct for those second-order errors.

In the surface code framework, the smallest logical qubit that corrects for both phase (Z) and bit flip (X) errors needs 17 physical qubits. A fully fault-tolerant quantum computer based on the surface code assuming realistic error rates is predicted to require millions of physical qubits.

Figure 1(a) shows a schematic for a single logical qubit in a variation called the rotated surface code. The depicted logical qubit is built out of 49 physical qubits on a 5 × 5 square grid (representing 25 data qubits on the vertices and 24 ancilla qubits on the faces) and is tolerant to up to two general errors; a larger number of qubits would be needed to correct for additional errors using the rotated surface code architecture. Errors are detected by encoding the parity of the data qubits on the four vertices of each square onto the ancilla qubits on each face using the quantum circuits from figure 1(b). An error on the data qubit will flip the parity of the neighboring ancilla qubits, allowing the error to be triangulated through ancilla qubit measurements. A logical bit flip gate is performed by individual bit flip gates along the logical X boundaries (indicated in red). Likewise, phase gates along the Z boundaries (in blue) accomplish a logical phase flip. During computation, the physical qubits are initialized as eigenstates of both X and Z stabilizers, operators like XXXX and ZZZZ that track bit flip parity and phase flip parity respectively, and are maintained in these states by X and Z parity checks performed by the circuits, as shown in figure 1(b).

A logical qubit consists of nine physical qubits and corrects for phase and bit flip errors on the data qubit.

Hybrid Quantum Computing

Quantum computing devices are now available through cloud services both freely to the public and as commercial offerings, including up to 20-qubit devices on superconducting qubit platforms. While these devices mark significant advances in the field of quantum computing and may be referred to as "quantum computers," they are far from the ultimate goal of fault-tolerant universal quantum computers. They are noisy and contain small enough numbers of qubits that they can still be simulated classically (although they are quickly approaching the limits of classical simulation).

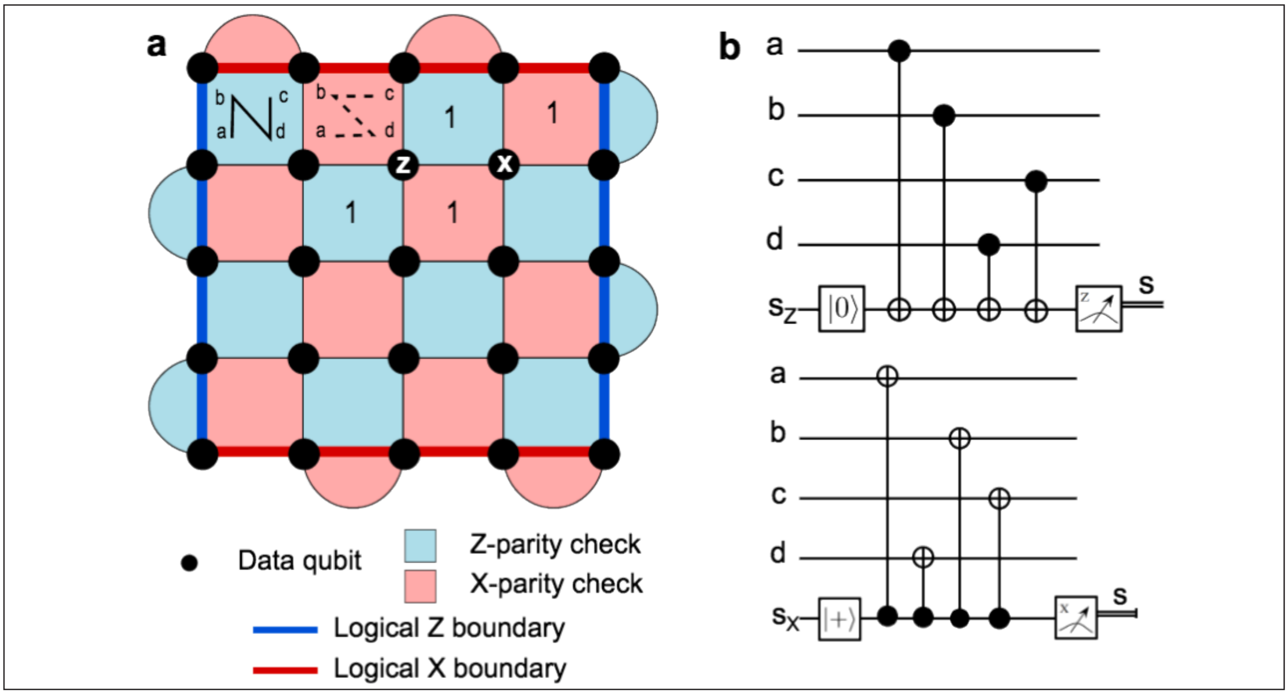

FIGURE 1 (a) Schematic of a rotated surface code, which consists of a square lattice with data qubits (round black circuits) on the vertices and ancilla qubits on the colored square faces. Z- and X-parity of four data qubits, such as the set {a,b,c,d} in the top left corner, are encoded into Z- (blue) and X- (pink) syndrome qubits using the circuits in (b). The ancilla qubit is measured at the end of the circuit. If no error occurred the qubit is measured to be $|0\rangle$. If a bit flip occurs, such as on the data qubit labeled "Z," the parity check on the neighboring Z-check qubits will measure $|1\rangle$ (using the circuit from 1(b) top); likewise for a phase flip on the data qubit labeled "X" and its neighboring X-parity check measurements (1(b) bottom). Reprinted from Gambetta et al. (2017), which was published under a CC BY license (Creative Commons Attribution 4.0 International License).

Near-term devices pose an interesting problem, however: once devices have enough qubits and can perform long enough depth circuits that they cannot be classically simulated but do not have error correction, can they do anything useful? While development of fault-tolerant quantum algorithms remains a vigorous area of active research, the availability of noisy intermediate-scale quantum devices is stimulating new efforts to find applications that do not require fault tolerance. These applications may include quantum chemistry (Kandala et al. 2017; Yung et al. 2014), optimization, and machine learning.

Recent experiments have demonstrated hybrid quantum-classical algorithms such as variational quantum eigensolvers (VQE) (Farhi et al. 2014; McClean et al. 2016). These experiments are less sensitive to gate errors because they involve a classical optimization step. The procedure is to prepare a trial state on the quantum processor and then measure some observables (how the state is prepared and which observables are measured depends on the problem being solved); then, based on those observables, the state preparation parameters are updated on a classical computer and run again until a minimum value is achieved. For example, Kandala and colleagues (2017) use VQE to find the ground state energy of small molecules.

In chemistry experiments, a fermionic Hamiltonian is mapped to qubits (Bravyi et al. 2017; Kandala et al. 2017). The trial state is prepared by applying a sequence of alternating single qubit gates and entangling steps, where each single-qubit gate is parameterized by three phases that determine the single qubit rotation caused by the gate. Then the observables that correspond to the qubit Hamiltonian are measured and the energy for that state is calculated. The classical computer updates the phase parameters according to a minimization algorithm (simultaneous perturbation stochastic approximation for this work; Spall 1992), and the cycle repeats until a minimum energy is found. The process is depicted in figure 2.

This approach is called hybrid quantum computing or approximate quantum computing. In addition to hav-

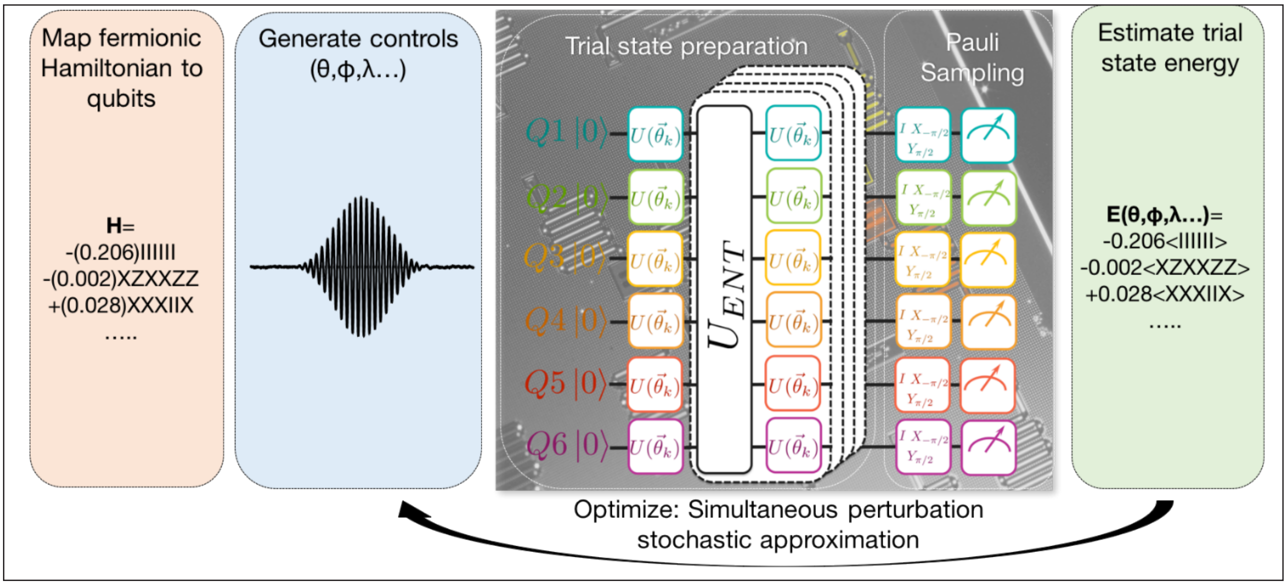

FIGURE 2 Steps for finding ground state energy using variational quantum eigensolvers. First (far left) a fermionic Hamiltonian is mapped to a qubit Hamiltonian, whose operators will be the quantities measured at the end of the loop (far right). Controls, generated by classical electronics, are parameterized so that they can be updated on each iteration of the optimization algorithm. The controls are made up of sequences of single qubit gates, $U(\vec{\theta}_k)$, interleaved with an entangling set, U_{ENT}. The controls are then applied to the quantum device, the observables from the first step are measured, and the energy corresponding to the qubit Hamiltonian is calculated. This process repeats with new $\vec{\theta}_k$ until the procedure converges on the minimum energy. Figure adapted from Kandala et al. (2017), which was published under a CC BY license (Creative Commons Attribution 4.0 International License).

ing inherently looser requirements on error rates thanks to the optimization process, these experiments can be further improved by techniques like error mitigation (Kandala et al. 2018), which works when the errors all scale with the length of the gates applied during the experiment. One can run the original experiment once and then repeat with all operations slowed down. The repeated experiment will have larger errors, but the two sets of data can be used to extrapolate to the zero-noise limit via Richardson (1911) extrapolation.

Looking Forward

The outlook for quantum computing involves pursuing both long- and near-term goals. Fault-tolerant universal quantum computing will require improving physical qubits to meet error correction thresholds, building devices with logical qubits, and developing new codes with less stringent requirements on numbers of physical qubits or error rates. In the meantime, there is hope that hybrid quantum-classical approaches such as the chemistry experiment described above will demonstrate a quantum advantage long before fault-tolerant devices are available.

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Advances in quantum simulation and manipulation have opened the door for the development and application of quantum technologies.

Quantum Simulation:
Advances, Platforms, and Applications

Norman Yao is an assistant professor in the Physics Department at the University of California, Berkeley.

Norman Yao

Nearly four decades ago, Richard Feynman gave a visionary lecture, "Simulating Physics with Computers," in which he emphasized the impossible complexity of simulating a quantum mechanical system using a classical computer (Feynman 1960, 1982). Indeed, even describing the full quantum state of ~60 electron spins is well beyond current computational capabilities. To overcome this challenge, Feynman proposed the notion of a "quantum simulator."

The intuition is strikingly simple: Make use of fully controllable quantum building blocks to mimic the interactions that underlie a less accessible quantum system (Buluta and Nori 2009; Lloyd 1996). Experimental progress in this direction has been truly extraordinary, making it possible to isolate single microscopic particles (at the nanoscale), to manipulate and control their internal quantum states, and to detect them with almost perfect fidelity (Cirac and Zoller 2012; Georgescu et al. 2014).

This paper describes three of the major experimental platforms associated with quantum simulation—ultracold atomic systems (Bloch et al. 2012), polar molecules (Moses et al. 2017), and superconducting quantum bits (qubits) (Houck et al. 2012)—and gives examples of the phenomena they can simulate.

Many-Body Phases in Ultracold Atomic Systems

Ultracold quantum gases provide a number of unique opportunities when it comes to simulating nature. They offer a tremendous amount of control, can be imaged with single-atom resolution, and can mimic the underlying structure of solid state materials (Bloch et al. 2012; Cirac and Zoller 2012). In addition, perhaps the most crucial aspect underlying their broad scientific impact is the existence of a flexible array of cooling techniques that can quench the kinetic energy of atomic systems. Indeed, ultracold atomic systems have actually reached subnanokelvin temperatures, revealing phenomena ranging from Bose-Einstein condensation and Cooper-paired superfluidity to Mott insulators and localization.

Ultracold atomic simulations have raised the possibility of studying topological phases in out-of-equilibrium spin systems.

Despite these successes, the temperature of atomic quantum simulations is still too high to simulate a number of more exotic[1]—and delicate—quantum mechanical phases, including antiferromagnetic spin liquids, fractional Chern insulators, and high-temperature superconductivity. The figure of merit for observing such physics is not the absolute temperature but rather the dimensionless entropy density.

Reaching ultralow entropy densities remains a major challenge for many-body quantum simulations despite the multitude of kinetic cooling techniques. This challenge is particularly acute for gases in deep optical lattice potentials, for which transport, and thus evaporative cooling, is slowed. Moreover, in lattice systems representing models of quantum magnetism, the entropy resides primarily in spin, rather than motional, degrees of freedom. Expelling such entropy through evaporative cooling requires the conversion of spin excitations to kinetic excitations, a process that is typically inefficient.

Two broad approaches have been proposed to overcome this challenge. The first is adiabatic preparation: one initializes a low entropy state and changes the Hamiltonian gradually until the desired many-body state is reached. However, the final entropy density is bounded from below by the initial entropy density, and experimental constraints or phase transitions may preclude a suitable adiabat. The second approach is to "shift entropy elsewhere" (Stamper-Kurn 2009) using the system's own degrees of freedom as a bath. This approach helps to stabilize the Mott-insulating phase of the Bose-Hubbard model, where the low-density wings of the system serve as an entropy sink, allowing for in situ evaporative cooling.

On the applications front, ultracold atomic simulations have raised the possibility of studying topological phases in out-of-equilibrium spin systems. Unlike traditional condensed matter systems, one cannot simply "cool" to a desired topological ground state by decreasing the temperature of a surrounding bath. Rather, preparation must proceed coherently. This necessitates both detailed knowledge of the phase transitions separating topological states from their short-range-entangled neighbors and understanding of the interplay of topology, lattice symmetries, and out-of-equilibrium dynamics.

One particular context where lattice and topology meet is in the notion of fractional Chern insulators–exotic phases, which (as explained in Yao et al. 2013) "arise when strongly interacting particles inhabit a flat topological band structure. Particles injected into these exotic states of matter fractionalize into multiple independently propagating pieces, each of which carries a fraction of the original particle's quantum numbers. While similar effects underpin the fractional quantum Hall effect observed in continuum two dimensional electron gases, fractional Chern insulators, by contrast, are lattice dominated. They have an extremely high density of correlated particles whose collective excitations can transform nontrivially under lattice symmetries." Since the full configuration interaction state generally competes with superfluid and crystalline orders, the resulting phase diagram exhibits both conventional and topological phases.

Spin Liquids in Polar Molecules

Polar molecules trapped in optical lattices have recently emerged as a powerful new platform for quantum simulation (Moses et al. 2017). This platform exhibits many

[1] "Exotic" in this context refers to two types of phases of matter: (1) those that have been theoretically predicted to exist but have not yet been observed in nature and (2) those that have been observed but are not yet fully understood.

advantages, including local spatial addressing, stable long-lived spins, and intrinsic long-range dipolar interactions. Typically, the molecules are subject to a static electric field and their motion is pinned by a strong laser field (figure 1). This implies that the degree of freedom, which (often) participates in the quantum simulation, is an effective rotational excitation.

These rotational excitations can simulate a large number of interesting many-body quantum phases. In particular, by varying the DC electric field strength as well as the tilt of the electric field vector, one can sharply modify the geometry of the dipoles and introduce additional dispersion into their single-particle band structures. At the same time, increasing the electric field strength enhances the long-range interactions. These qualitative differences in the microscopics of polar molecules yield a rich phase diagram exhibiting both conventional and topological phases, including crystalline ordering, superfluids, and chiral spin liquids. The nature of these phases can be characterized using diagnostics such as the ground-state degeneracy and the real-space structure factor.

Of particular interest in the context of polar molecular simulations is the realization of quantum spin liquids. These are characterized by entanglement over macroscopic scales and can exhibit a panoply of exotic properties, ranging from emergent gauge fields and fractionalized excitations to robust chiral edge modes.

Recent work has demonstrated that polar molecule simulations naturally realize the so-called dipolar Heisenberg antiferromagnet. Such simulation requires only a judicious choice of two molecular rotational states (to represent a pseudo-spin) and a constant electric field. The simplicity of this system stems from the use of rotational states with no angular momentum about the electric field axis and contrasts with previous works where nonzero matrix elements appear for the transverse electric dipole operator, unavoidably generating ferromagnetic spin-spin interactions. Motivated by this physical construction, large-scale numerical studies of the dipolar Heisenberg model (e.g., Yan et al. 2011) find evidence for quantum spin liquid ground states on both triangular and Kagome lattices.

Quantum Walks in Superconducting Qubits

Much like their classical stochastic counterparts, discrete-time quantum walks have stimulated activity across a broad range of disciplines. In the context of computation, they provide exponential speedup for cer-

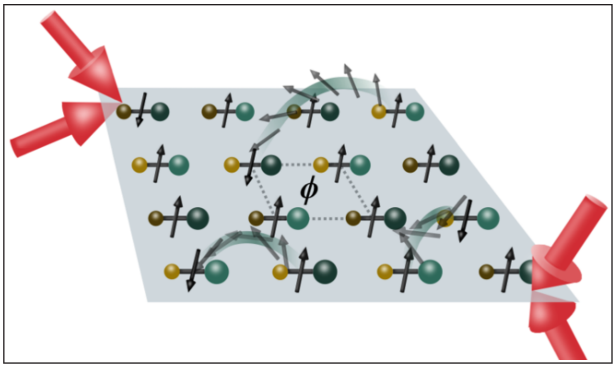

FIGURE 1 Polar Molecule Quantum Simulation. Schematic representation of two-dimensional array of polar molecules dressed by optical beams (red arrows). Each polar molecule is characterized as an effective pseudo-spin-flip, which can hop and interact mediated by the long-range dipolar interaction. ϕ = the angle of the electric field. Colored balls (e.g., green, gold) represent different quantum states of the molecules. Reprinted with permission from Yao et al. (2013).

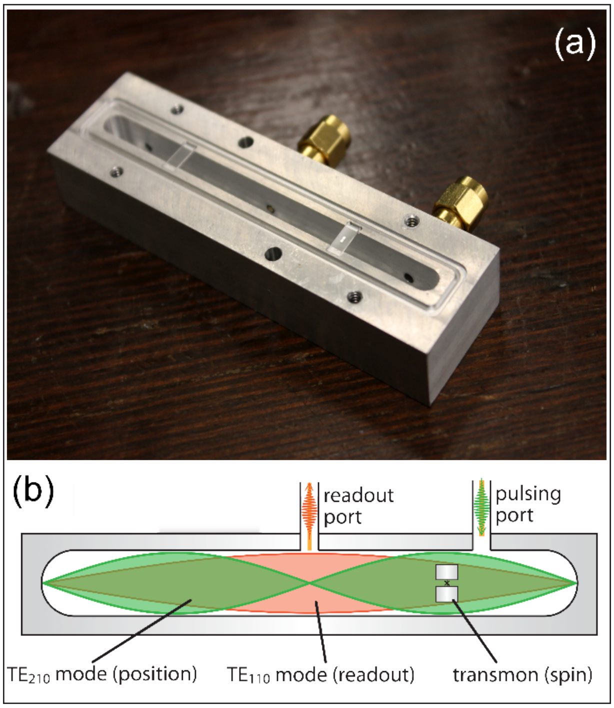

FIGURE 2 (a) Cavity resonator (aluminum box) and coupled superconducting transmon qubit. (b) Schematic of the simulation platform for quantum walks. The fundamental (TE_{110}) mode is used to measure the qubit state. The transmon qubit is dispersively coupled to both cavity modes. Reprinted with permission from Flurin et al. (2017).

tain oracular problems and represent a universal platform for quantum information processing. Quantum walks also exhibit features characteristic of diverse physical phenomena and thus are an ideal platform for quantum simulation.

It has recently been demonstrated that quantum walks can be directly realized using superconducting transmon qubits coupled to a high-quality-factor electromagnetic cavity (Flurin et al. 2017; figure 2). The quantum walk takes place in the phase space of the cavity mode and each lattice site corresponds to a particular coherent state of the cavity, while the two logical states of the superconducting qubit form the internal spin of the walker. Coherent spin rotations can be performed using microwave driving, while spin-dependent translations arise naturally from the dispersive coupling between the qubit and the cavity.

A unique application of this particular quantum simulation platform is in the direct measurement of so-called topological invariants. In these protocols, a geometric signature of the topological invariant is imprinted as a Berry phase on the quantum state of the particle; the phase can then be extracted and disentangled from other contributions via a simple interferometric protocol.

Conclusion

The quantum simulation community has made remarkable progress in the controlled manipulation of individual quanta (e.g., Lanyon et al. 2011; Simon et al. 2011). These advances have opened the door for the engineering of quantum many-body systems as well as the development of quantum technologies.

Looking forward, the continued dialogue between atomic, molecular, and optical physics, condensed matter physics, and quantum information science promises to be fruitful for both the fundamental and applied sciences, enabling the simulation of macroscopic quantum behavior and providing detailed microscopic intuition.

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Understanding the other "side" through a game framework can help response communities learn to coordinate with greater equity, efficiency, and impact.

Combining Formal and Informal Structures in Crisis Response

Willow Brugh, Galit Sorokin, and Gerald R. Scott

Willow Brugh

Galit Sorokin

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Crisis response is often highly fragmented; formal, informal, and ad hoc response entities all spring into action with little coordination or communication. Attempts to improve coordination during crises by synchronizing and planning outside of a crisis setting often fail because of either lack of representation from informal and ad hoc response groups or competing priorities and requirements in formal organizations.

Working with formal and informal response groups, this project sought to improve coordination by creating a game to help responders develop the knowledge, skills, and networking capacities necessary to interact and coordinate with each other in the field. We were able to codify traits of

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their capacities in a game format from which others can learn. We used a method for facilitation and engagement that optimizes for both the adaptability of the network (informal) and the predictability of the centralized (formal). Understanding the other "side" through this game framework can help response communities learn to coordinate with greater equity, efficiency, and impact.

This project was undertaken with two goals: (1) to foster a bridging process between the two response communities and (2) to develop a tool to improve crisis response by identifying and addressing systemic failures due to gaps between informal and formal crisis response groups. Our research covers the creation of the game and two iterations, but is not an in-depth qualitative study of the interactions that took place during game play. Further improvement of the game through play testing and iteration will allow it to be more playable and useful for its stated goals.

Introduction

Tabletop exercises—scripted sessions in which participants talk through how they or the organization they represent would respond to particular events—are a common tool that formal response organizations use to develop concepts and policies. Informal responders, while they may be represented at these sessions, seldom participate at the same level or frequency and so their viewpoints may go unrecognized (Perry 2004).

Understanding each other through a game framework can help response communities learn to coordinate with greater equity, efficiency, and impact.

During our 3-day workshop the sessions provided an opportunity for the development of understanding and cooperation between the formal and informal response communities and of organizational strategies that can improve resiliency, response, and recovery in the face of disasters. Through play testing and iteration during their time together, members of these polarized groups demystified their strengths and limitations by working together to design and create a card game usable during tabletop exercises or otherwise.

The game we developed is now playable by others and open to ongoing improvements. In fact, it has been used in training workshops conducted by offices of emergency services seeking to understand and improve the integration of volunteers and informal response organizations in their disaster response operations, and it led to insights for collaboration opportunities during the responses to Hurricanes Harvey and Irma.

This paper explains the problem, why building a game was the course of action chosen, the methods we used to create the game, and preliminary results.

Background: Formal and Informal Response Groups

Response organizations operate along a continuum from the very formal (organizationally stable, with consistent, slow-changing methods) to the very informal (organizationally dynamic, with frequently changing artifacts such as how-to guides and updates about ongoing work). In this paper we focus on the two ends of the spectrum to illustrate the most problematic disconnections in the system.

Formal Agencies

Official (formal) response agencies generally have either professional specialists or operational staff supporting response missions as well as articulated channels for accessing resources needed for response and recovery, but they create encumbered mobility of response and information (Quarantelli 1988). Formal disaster response agencies are (1) government organizations whose overall purpose or specific task is to respond (e.g., FEMA) or (2) nongovernment organizations that exist, plan, and train before the required response (e.g., the Red Cross).

The centralized, hierarchical structures for formal agencies' operations foster vertical communication in the organization but inhibit horizontal communication, particularly with external entities: Personnel know how to talk to who they're allowed to talk to, but that's it. And aid is delivered in big blocks of materials to pre-established points of relief that are accessible for mass deliveries and to majority crowds (Bharosa et al. 2010; Boin and 't Hart 2010; LaPorte and Consolini 1991). For people to receive this aid they must leave their home and be easily mobile, located within reach of a center, and able to use the material (which is made and packaged for large-scale distribution and consumption). They must also be “legible” to the state: documented citizens without any legal issues. Because of these parameters, often the populations most at risk (e.g., marginalized people, the disabled or elderly, undocumented immigrants) are the least likely to be assisted.

Informal Groups

Emergent (informal) response groups—such as Occupy Sandy (http://occupysandy.net/), the “Cajun Navy,” and volunteers in Mexico City after the September 2017 earthquake (NPR 2017)—form as a direct result of the crisis itself. They organize quickly through both local and digital networks, and include members of the local population, community leaders, and grassroots and nonprofit networks already established and operating in the area. Remote groups form through similar social and professional ties, but primarily via digital channels.

Informal response entities often have or are able to quickly gather high-resolution information and data. Neighborhood needs are rapidly assessed, support and failure points are known, and local knowledge is quickly disseminated. But they may be unable to respond out of their own capacity, as local material or services are scarce and access to appropriate resources is extremely limited, if available at all. Informal groups may have a comprehensive mapping of pocket populations and their needs, but lack the professional abilities to anticipate and document resource needs, let alone deliver the necessary relief (Sobel and Leeson 2006; Whybark 2007). Large-scale recovery operations—such as removal of debris, provision of acute medical care, and restoration of critical infrastructures—tend to be beyond their scope (Majchrzak et al. 2007).

The Need for Coordination

Given the complementary capabilities, knowledge, resources, information, and access of formal and informal response groups, the potential for increased efficiency, recovery, and accessibility and decreased response time, duplication of efforts, and waste is immense. Yet there are few channels for such coordination, and even less trust between formal agencies and informal groups. Lack of visibility into one another’s operations, limited understanding of logistical mechanisms, and cultural differences contribute to the lack of trust (Shklovski et al. 2008).

Faced with this challenge, it is tempting to simply encourage the two actors to behave in ways more similar to each other—the informal more predictably, and the formal with more agility (Harrald 2006; Mendonça et al. 2007). But closing the systemic gaps hinges on an understanding between the two sectors, making their operational abilities visible to each other. With understanding comes trust and a willingness to coordinate. When trust is established, dividing tasks and responsibilities becomes part of the response process as information becomes reliable and actors (and their actions) are accountable to a shared mission. Failure to collaborate impacts all crisis responders and the populations affected by their efforts.

Failure to collaborate impacts all crisis responders and the populations affected by their efforts.

The disconnect between formal and informal response systems arises in part from cultural differences (Schneider 1992; Shklovski et al. 2008; Yates and Paquette 2011). “The government” is considered untrustworthy and unreliable to grassroots-level responders, whether because of its bureaucratic structures and histories and perceived agendas or because of a cultural and operational disconnect. And because grassroots groups and their efforts are not formally vetted, hierarchically accountable, or catalogued in a referential manner, formal institutions do not consider them trustworthy or reliable for strategic integration in their efforts.

Visibility and, where possible, transparency open up possibilities for collaboration and cooperative problem solving. Understanding how other groups operate can lead to suggestions for mutual courses of action. Formal and informal response groups working effectively together create a more holistic response ecosystem, with fewer gaps and greater relief capacities (Bharosa et al. 2010; Majchrzak et al. 2007).

To begin the bridging process, this project brought together different types of response groups with the intent of increasing cross-visibility, codifying understanding, and developing trust to improve crisis response.

Organizational Theory, Collaboration, and Cooperation

Formal organizations share certain characteristics—some level of hierarchy, bureaucracy, and norms of internal and external communication—that can be used in organizational theory models to describe and enhance understanding of how they function. Bureaucratic political theory, epistemic community theory, and game theory each provide insights on how cooperation and collaboration[1] can develop in an often discordant emergency response ecosystem (Scott 2003).

Bureaucratic Model of Organization

Allison and Halperin (1972) provide a bureaucratic model of organizations based on three variables: who plays, what determines a player's position, and how positions are aggregated into an outcome. The model assumes that cooperation is not the natural state of affairs. The authors describe a noncooperative bargaining process in which "organizations rarely take stands that require elaborate coordination with other players" (Allison and Halperin 1972, p. 49).

Visibility and transparency open up possibilities for collaboration and cooperative problem solving.

The authors argue that a player's stand is largely determined by both the institutional goals and biases that the player represents and the player's personal goals. The model is helpful in our context for understanding why players might take a position that does not support efforts to address a disaster. In addition to the response at hand, individuals representing a formal organization may be concerned about other things such as availability of resources for future needs, public image, hierarchical pressures not related to the response, or the security of organizational information and systems. Such concerns may draw the players' (disaster responders') positions further apart as they seek to increase their personal or organizational position, power, and/or resources.

On the other hand, the Allison-Halperin model allows for organizational motivations that move the positions closer together or make cooperation more valuable. These motivations might include the potential to improve the disaster response, an inability to meet certain organizational response tasks, or insufficient resources.

Epistemic Community Theory

Epistemic community theory suggests that cooperation can arise among members of various organizations even when there are significant bureaucratic barriers to it. According to Haas (1992, p. 3), "an epistemic community is a network of professionals with recognized expertise and competence in a particular domain and an authoritative claim to policy-relevant knowledge within that domain or issue-area." Although Haas was writing about international politics, epistemic communities are also found in the disaster response ecosystem. Responders and emergency managers move from organization to organization, attend conferences together, and work together in training exercises and events. Strong epistemic communities help to create trust among individuals across organizations, allowing for cooperation and collaboration even without a bureaucratic mandate for them.

In an alternative model, Axelrod (1984) shows how cooperation can evolve and that an organization's strategy in responding to the actions of other organizations can significantly impact how the cooperation progresses. In Axelrod's model, reciprocation consistently breeds cooperation (pp. 155–158). Variations of this strategy that include some level of "forgiveness" for "defection" can be even more effective.

Game Theory

Recently there has been more focus on deliberate change in organizations seeking innovation and improved collaboration, using models and techniques that shift the focus of leaders from "directing" to "enabling" by supporting initiative and risk taking at all levels. The resulting changes (1) have been endorsed by all types of organizations (although they are implemented more readily by organizations that are less rigidly hierarchical), (2) often lead to more intra- and extramural collaboration as individual efforts to collaborate are supported by leadership (Hoskisson et al. 2017), and (3) illustrate the utility of a game-theoretical model of organizational change and collaboration (Arsenyan et al. 2015).

[1] For this game, "cooperation" means simply "staying out of each other's way" and "collaboration" implies actively working to the benefit of the other.

Other changes in organizational norms—such as recognition of the usefulness of play in work (Vesa et al. 2017), the use of design thinking as a mechanism of organizational change (Brown 2009), and globally distributed teams (Jimenez et al. 2017)—can make the use of games a potentially transformational means to improve interaction between the formal and informal aspects of disaster response.

The Project

In creating and play testing the game, we focused on reducing duplication of effort between formal and informal organizations to support more effective placement of resources; on understanding how trust impacts the ability and motives of various actors; and on building visibility and trust between the different groups.

The objective of the game was to create understanding about why some actors behave the way they do and to thereby create a faster feedback loop around lack of collaboration and ineffective response. The game is meant to instill frustration as systems-level issues become apparent and players who can see each other cannot interact because of arbitrary and stale system mechanics they themselves have perpetuated. Players are encouraged to create new rules to the game, and these may affect how they comport themselves before and during response.

Methods

We undertook this project as action research because it (1) presents a problem that warrants immediate implementation of identified solutions and (2) involves members of both the formal and informal disaster response communities in the identification, design, and development stages (Creswell 1998). We began with several questions about the use of game play:

- Can we create a game that adequately approximates the structure and dynamics of a disaster response ecosystem?
- Does the use of such a game in an organizational setting identify common, recurring, and detrimental barriers to collaboration?
- Does game play induce strategies of cooperative reciprocity among participating individuals and organizations?
- Does use of the game open up opportunities for exploration that other methods don't?

Gioia and Chittipeddi (1991) provided the methodological foundation for this research. Their study concerned an effort of deliberate change, and the goal of our game-building project was similarly to instigate change in how formal and informal organizations interact in disaster response.

Selection of Game Development Team

To represent formal and informal perspectives, invitees for the game creation group were from local response groups (the Empowered Communities Project, San Francisco Department of Emergency Management, Salvation Army Crisis Response); international NGOs (Save the Children, Oxfam, UNICEF); the private sector (Microsoft, Monkey Brains, Cisco, Airbnb); nonprofits (Meedan, Public Labs, Sarapis, Open Referral, Benetech); and informal groups (Occupy Sandy, anarchist responses to the refugee crisis).

> *An organization's strategy in responding to the actions of other organizations affects cooperation: reciprocation breeds cooperation.*

Nine individuals were able to participate: three from informal response entities, two from formal response organizations, one from a nonprofit, two from cross-sector coordination groups, and one from the private sector.

3-Day Workshop for Game Design

Day 0

- Participants established trust before the start of the planned activities through unstructured time and meals together.

Day 1

- A "Universe of Topics" exercise captured participants' feelings and ideas so that they each felt heard and could see how much/how little their goals overlapped.

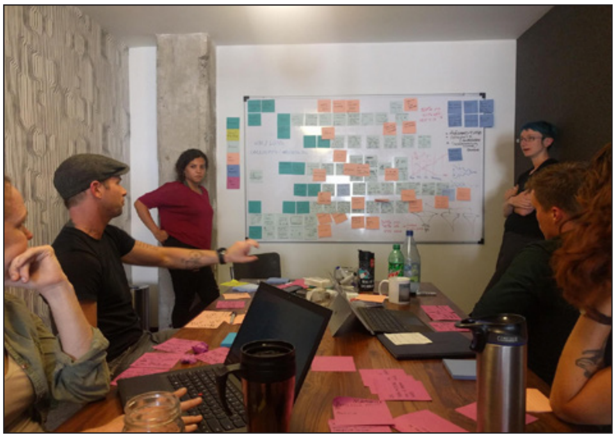

FIGURE 1 Participants in a game design session posit game factors such as players (teal notes), resources (blue notes), and pain points (coral notes). Photo by Drew Hornbein.

- Participants did a visual thinking exercise to describe how their ecosphere works.
- Participants posited some factors for a game (e.g., players, resources, pain points; figure 1).

Day 2

- Participants played Pandemic (a board game in which players work as a team to treat infections around the world while gathering resources for cures) to immerse in game mechanics and instigate conversation.
- Individuals proposed their own game structures and gave each other feedback.
- Participants explored shared factors of their proposed games to coalesce around one game model to develop further together.
- Participants made a prototype, troubleshooting the parts that didn't work. It was okay to be wrong.

Day 3

- Participants visualized the game flow to identify effective aspects (figure 2).
- Play testing revealed what parts were unclear, imperfectly designed (e.g., a player comes out ahead because of ill-conceived math rather than a well-played game), or superfluous.
- The game was revised based on these discoveries and play tested a second time.

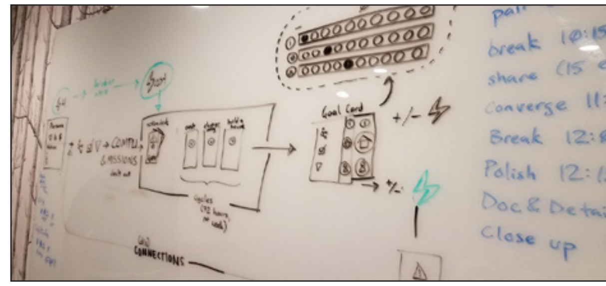

FIGURE 2 Workshop participants illustrated the game flow to identify effective aspects.

- Participants documented how the game works and next steps (while it was fresh in people's minds).

Results

The nine participants produced and have since play tested our prototyped card game. It is called ENCAPE (Emergent Needs, Collaborative Assessment, and Plan Enactment) and has four parts:

- a how-to-play guide;
- a 98-card deck for 4 "personas" (Concerned Citizen, Ad Hoc Response Network, International NGO, and Municipal Government[2]) with 4 connection cards (for one persona to team with another and share resources), 20 special resource/action cards specific to each persona, 30 resource/action cards for any player, 10 missions, 30 updates;
- templates to generate more cards of each type; and
- a process for capturing and enacting feedback from play testers.[3]

The game reveals how different player types behave, how duplication of efforts and subsequent waste impact the response ecosystem, and how working together might enhance response efficiency.

Implications

While much research has been done into the workings of formal structures, and some into informal structures, very little has been done into how they overlap or what the costs and benefits of doing so might be. ENCAPE

[2] The game still lacks the private sector lens, something we hope to remedy in further play testing.

[3] These resources are available via links at http://blog.bl00cyb.org/2017/08/interfaces-between-formal-and-informal-crisis-response/.

revealed two main areas for improvement in disaster response specifically through cooperation or collaboration in formal and informal efforts: deduplication of efforts and reduction of waste.

Duplication of Efforts

During every crisis there are a few predictable challenges, such as calls for help from stranded or endangered people, individuals separated from their loved ones, basic needs for resources. Although these are well-known and expected elements of a crisis, efforts to address them are often duplicated by formal and informal groups. There is some coordination among groups, but it is limited to one "side" of the spectrum or the other: formal entities share with other formal entities when allowed to, and informal groups share with other informal groups when they are visible to each other.

It is not possible to avoid all duplication of effort. Even formal groups are forced into coordination during a response, regardless of investment of resources in precrisis partnerships. The informal sector is by definition unorganized until an event occurs, with energy expended in doing what they can rather than in becoming familiar with existing resources.

Waste of Resources

Lack of coordination and collaboration can be obvious in the lack of sufficient resources in some places and an excess in others. ENCAPE focuses on three types of resources:

- Information is necessary for understanding needs and context. Waste in this area shows up as information overload due to lack of data structures (the information becomes overwhelming and inactionable).
- Materials are necessary for medical services and rebuilding homes, for example. They are wasted when left unallocated or unused (e.g., food rotting on runways) because of unpredictable variation in need-supply flows or complications in distribution.
- Labor is necessary for the use of both information and materials. Ineffective volunteer and employee management results in a paralyzed workforce constantly seeking direction or permissions, unable to mobilize in a focused and timely manner. This causes a loss of trust in the organization's ability to act intelligently or be worth showing up for.

Cautions about Findings

This paper describes the impetus and workshop that generated a game to improve understanding of opportunities and barriers in crisis response coordination and collaboration. Deep qualitative research (transcription, coding, and analysis) of the workshop and additional play testing sessions are needed. Much of the understanding of formal/informal issues comes from the authors' direct experience working with emergency response groups.

The game instills frustration as players cannot interact because of arbitrary and stale system mechanics they themselves have perpetuated.

Future Research

While some research focuses on informal organizational structures, it is nowhere near as broad or deep in the disaster response sector as research on formal organizations. Benefits from the combination of these two methods will require a deeper understanding of each, as well as of the consequences of doing so.

Acknowledgments

The research described here was funded by the Office of the Secretary of Defense through the Naval Postgraduate School (NPS) Joint Interagency Field Experimentation and performed for Georgia Tech Research Institute by Willow Brugh. Joint Interagency Field Experiments (JIFX), week-long collaborative learning events hosted quarterly by NPS, bring together representatives from academia, technology industries, NGOs, and governments (local, state, federal, and international) to explore the application of emerging technologies to meet government needs and improve humanitarian and disaster response capabilities. One outcome of JIFX has been the development of a collaborative culture among participants. Topical working groups and design groups often run in parallel with technology experiments; the game development sessions described here were one such activity.

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Engineers need to better understand climate-infrastructure interactions and develop strategies in engineering design practice to account for the effects of climate change.

Climate Change and Infrastructure Resilience

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Firas Saleh

Infrastructure for energy, transportation, and water has evolved over time into inextricably interconnected systems. Traditionally, the engineering design practice of such systems has proceeded on the assumption of "climate stationarity," in which the frequency and magnitude of weather patterns remain unchanged into the future. But climate change is introducing nonstationary stressors such as rises in sea level and temperature and more frequent and intense storms. Such stressors can affect infrastructure systems at varying spatial and temporal scales and require a holistic understanding.

Recent extreme events have highlighted the importance of understanding infrastructure interdependencies to strengthen resilience and adaptive capacity in a changing climate. Hurricanes Sandy (2012), Harvey (2017), Irma (2017), and Florence (2018) caused disruptions to major US water, transportation, and energy systems that affected the functioning of other critical infrastructure (e.g., for health care and telecommunications). Resilience planning must account for the impacts of both disruptive extreme weather events and long-term climate change–induced stressors such as sea level rise and drought.

The work presented here focuses on the use of state-of-the-art modeling techniques to better understand the infrastructure impacts of natural (e.g., storms and floods) and anthropogenic (e.g., dam breaks) hazards as well as gradual stressors (e.g., sea level rise). This multidisciplinary research merges the fields of climate change; civil, water resources, and coastal engineering; remote sensing; and high-performance cloud computing to identify critical thresholds in aging infrastructure and failure cascade risks in interconnected systems.

Introduction

Climate change is expected to alter the intensity, duration, and/or frequency of climatic extremes over time, a concept termed nonstationarity (Cheng and AghaKouchak 2014).

In general, engineering design metrics and assessment of risk are based on historical statistical analysis in which hydrologic processes fluctuate in an unchanging envelope of variability. Such metrics are essential in guiding engineering design choices.

In inland and coastal urban areas, nonstationary processes are exacerbated by anthropogenic land-cover changes such as deforestation, urban expansion, and water diversion. In a changing climate, frequent and more intense storms can have more serious implications for vulnerable and aging infrastructure.

Long-term sea level rise is the main driver of accelerated flooding along the US coastline; however, changes in joint distributions from storm surges and precipitation associated with climate change also augment flood potential (Sweet and Park 2014). Hurricane Irene (2011), for example, showed that with a compound event such as storm surge and heavy precipitation, the potential for flooding in low-lying coastal areas is much greater than from either in isolation. Irene's extreme rainfall and resulting flash floods in New York, New Jersey, New Hampshire, and Vermont destroyed or damaged nearly 2,400 roads and 300 bridges (Saleh et al. 2016, 2018a, 2018b). Tropical storm Harvey in 2017 brought more than 51 inches of rain in Texas, breaking the record for the greatest amount of rain recorded from a single tropical storm or hurricane in the continental United States.

The combination of aging infrastructure and increasingly severe climatic stresses sets the stage for future disasters. In that context there is a pressing research need to develop strategies for engineers to (1) better understand climate-infrastructure interactions to recognize the limits and opportunities of the knowledge base on which decisions will be made; (2) account for the effects of climate change in engineering design practice, where appropriate; and (3) clearly justify when such changes are *not* needed for a project of a particular type or scale.

There have been significant advances in considering climate change information in coastal areas, owing to the availability of sea level rise scenarios and analytical methods and tools. But there remains insufficient knowledge of inland and estuarine areas and their preparedness for compound events.

Use Case: Dams and Storm Events

Throughout the United States more than 90,000 dams provide important service and protection to communities and the economy. Their average age is 56 years, which exceeds the average life expectancy of 50 years for certain dams.

Dams are classified based on their hazard potential: high, significant, or low (table 1). As US population grows and development continues, the number of high-hazard dams is increasing—it was nearly 15,500 in 2016 (see, e.g., figure 1). Many dams were designed based on relatively short hydrologic records; longer accurate instrumental records and future climate modeling are needed to guide their upgrading as well as the construction of new dams.

Overtopping is one of the most common forms of catastrophic dam failure, and may result from an increase in the frequency and intensity of extreme rainfall. In addition, as water levels rise from increased inflows, structural and hydraulic stresses from the weight of the additional water in the reservoir will

TABLE 1 Dam hazard classification. Based on ASCE's 2017 Infrastructure Report Card (https://www.infrastructurereportcard.org/cat-item/dams/).

Hazard classification	Potential consequences of failure or misoperation
High hazard	Loss of life; significant economic losses, including damages to downstream property or critical infrastructure, environmental damage, or disruption of lifeline facilities
Significant hazard	Significant economic losses, including damages to downstream property, critical infrastructure, environmental damage, or disruption of lifeline facilities
Low hazard	Minor damage to nonresidential and normally unoccupied buildings, or to rural or agricultural land

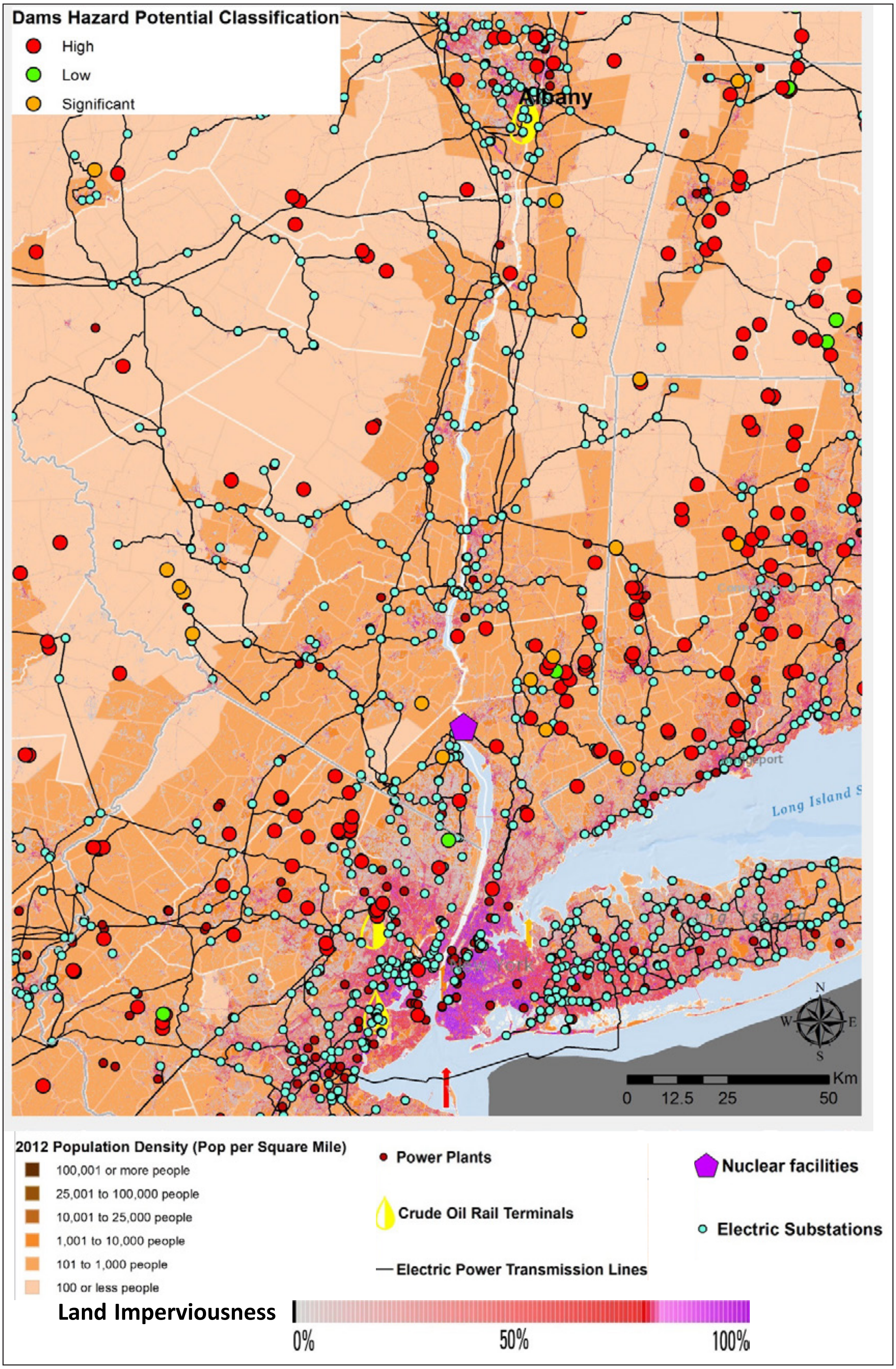

FIGURE 1 Interconnected critical infrastructure in the Lower Hudson Basin, New York.

likely exceed levels either designed for or previously experienced in a given dam.

It is often the case that man-made and natural disturbances do not happen in isolation and their impacts can vary temporally and spatially. Such compound events are likely to cause tipping points and major disturbances to dams and other critical infrastructure. To address this aspect, a predictive framework was developed in this work to evaluate implications of man-made-induced and natural disturbance scenarios such as storm surges and intensive rainfall storms that trigger dam overtopping or a dam break.

Overtopping is one of the most common forms of catastrophic dam failure, and may result from increases in the frequency and intensity of extreme rainfall.

A test bed located in a complex estuarine system in northern New Jersey (figures 1 and 2) was selected to critically evaluate infrastructure resilience for extreme flood events associated with hurricanes Irene (2011) and Sandy (2012). The two events emphasize the importance of detailed integrated modeling for compound effects of coastal storm surge and riverine flooding.

The test bed captures long- and short-term stressors:

- a coastal environment subject to sea level rise;
- a steep gradient in population density;
- an infrastructure serving one of the largest metropolitan areas in the United States;
- a highly urbanized area with valuable commercial and residential assets;
- a history of environmental impacts, ranging from heat waves and hurricanes to localized storms; and
- a wealth of historic and real-time data and extensive monitoring facilities.

The area is bounded on the west by the Passaic River at Dundee Dam, on the north by the Hackensack River at New Milford (downstream of Oradell Reservoir, built in 1923), on the east by the Hudson River, and the tidal influence of Newark Bay from the south (Saleh et al. 2017).

To establish baseline inundation extents, the inland hydrodynamic component of the modeling framework was forced with the best available data from the United States Geological Survey (USGS) and National Oceanic and Atmospheric Administration (NOAA), represented by measured river discharge and ocean water levels (figure 3). The extents simulated by the model for Hurricane Irene were a combination of storm surge and major flooding. In contrast, flooding associated with Hurricane Sandy was dominated by a coastal storm surge that overtopped all berms and several tide gates in the area of study. The analysis for Hurricane Sandy suggests that the storm surge propagated 36.2 km inland along the Hackensack River up to the Oradell Reservoir dam (figures 2 and 3).

Upon establishing baseline conditions, the framework was then forced with probabilistic and scenario-based projections of sea level rise and change in rainfall to help stakeholders and practitioners understand long-term risks in a changing climate.

Discussion and Conclusion

Modeling frameworks representing hydrosystem components spanning numerous temporal and spatial scales were integrated to provide telescopic capabilities for modeling coastal and inland flooding. The modeling outputs provide important information to quantify integrated processes at decision-relevant scales, identify significant vulnerabilities, and mitigate associated high-impact risks in critical infrastructure. The framework can be used to quantify the impacts on the paired bilateral interfaces of energy-water from natural (e.g., storms and floods) and anthropogenic (e.g., dam break) shocks and explore complex interactions with gradual stressors (e.g., climate change and changes in land use).

Compound events are characterized as (1) two or more extreme events occurring simultaneously or successively (e.g., storm surge, hurricane, Nor'easter, dam failure, and/or precipitation-induced high river discharge), (2) the combination of one or more extreme events and underlying conditions that amplify the impact of the event(s) (e.g., excessive soil moisture, drought, prolonged heat wave), or (3) combinations of

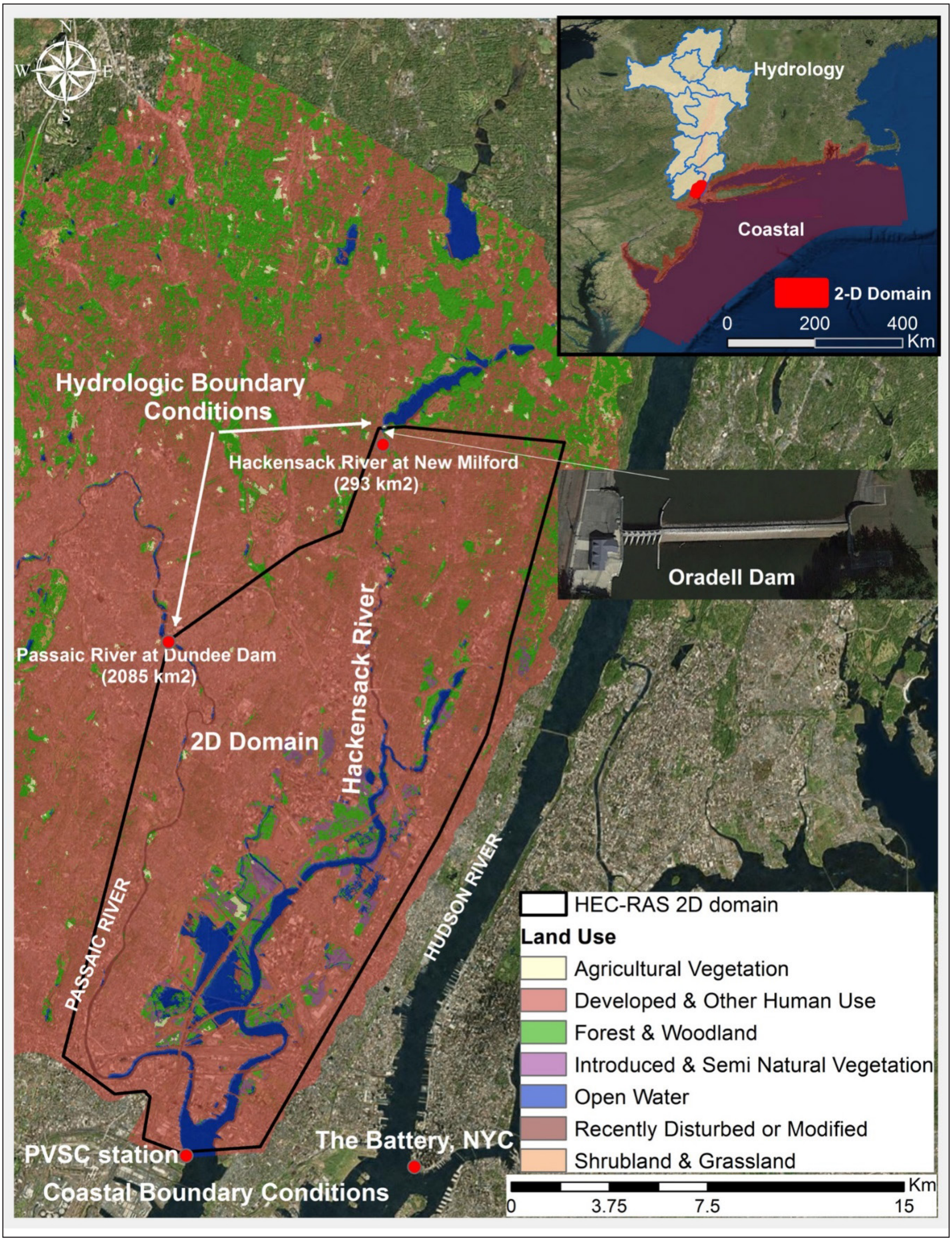

FIGURE 2 Test bed in northern New Jersey showing interconnected system and multiscale modeling components. HEC-RAS = Hydrologic Engineering Center River Analysis System of the US Army Corps of Engineers; NYC = New York City; PVSC = Passaic Valley Sewerage Commission.

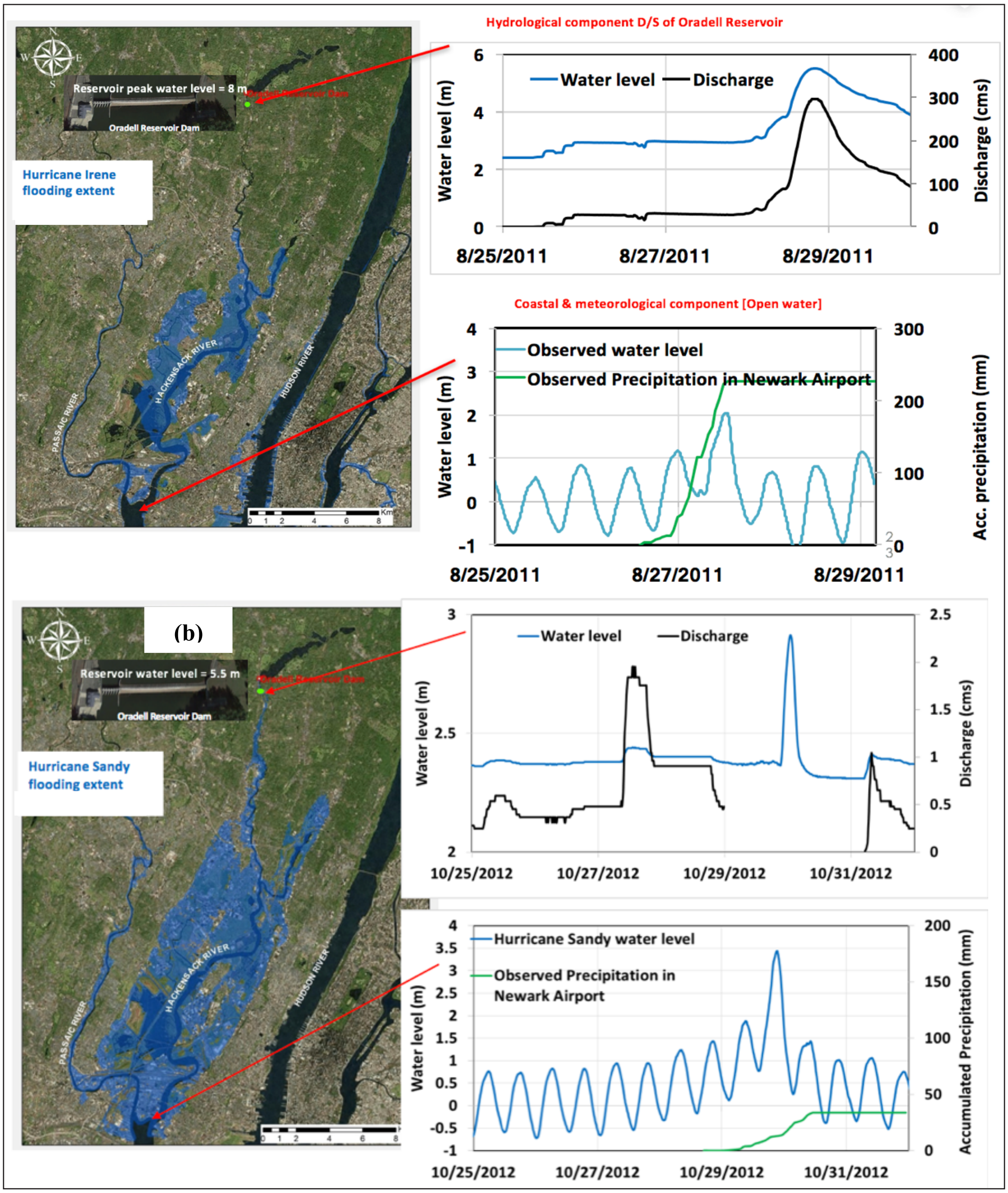

FIGURE 3 Flooding extent for the combined impact of riverine and tidal components during (a) hurricanes Irene and (b) Sandy showing the observed accumulated precipitation and coastal water levels (including surge) at Newark Bay. D/S = downstream

events that are not themselves extreme but create an extreme event or impact when combined (e.g., saturated soil, snow melt with temperature anomalies).

Coupling the system-level models of the framework with regional-scale climate change projections can help identify strong and weak linkages between the different components and nonlinear behaviors and responses across spatial and temporal scales. The resulting information can be used to guide decisions about the capacity of infrastructure to withstand projected climate-related hazards.

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The development and refinement of targeted theranostic nanoparticles may advance progress in treating cancer.

Developing Targeted Theranostic Nanoparticles:

Challenges and Potential Solutions

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It has been nearly 50 years since President Richard Nixon declared "War on Cancer" with the National Cancer Act of 1971. Yet according to the Centers for Disease Control and Prevention[1] the cancer death rate has decreased by only about 20 percent since then, paling in comparison to the >65 percent reduction in the death rate for heart disease and stroke (Ma et al. 2015). The development and refinement of targeted theranostic nanoparticles may advance progress on this front.

Introduction

The vast majority of cancer chemotherapeutics, which primarily consist of small-molecule drugs, have failed to make a major impact on the death rate for most cancer types. This can be at least partially attributed to the substantial risk of systemic toxicity, which limits the dose that can be safely administered. Because of the body's rapid clearance of small-molecule drugs, high doses are needed to achieve a therapeutic effect, but since drugs perfuse both diseased and healthy tissue, there can be undesirable effects in the latter. Small-molecule drugs are also often associated with broad mechanisms of action, which can disrupt unintended cellular pathways.

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[1] Expected New Cancer Cases and Deaths in 2020, https://www.cdc.gov/cancer/dcpc/research/articles/cancer_2020.htm.

Initially, it was thought that nanoparticles would provide an immediate solution to all of these problems. Nanoparticles used in therapeutic applications are typically produced at sizes of 10–150 nm to ensure long circulation times after intravenous administration. In general, drugs of less than 10 nm are rapidly cleared by the kidneys, and nanoparticles larger than 150 nm are more efficiently cleared by phagocytic Kupffer cells in the liver. Nanoparticles are also designed to be biocompatible (so they do not elicit a significant immune response) and biodegradable (to ensure eventual excretion).

Imaging agents and therapeutic agents are used to facilitate the study and evaluation of nanoparticle pharmacokinetics. Nanoparticles prepared with both a therapeutic and diagnostic imaging agent are often referred to as "theranostic."

Advantages and Challenges of Nanoparticle Drug Delivery

There were many reasons for the initial excitement surrounding nanoparticles as drug delivery vehicles. First, their circulation half-life in serum can be 10- to 100-fold longer than the small-molecule drugs that they carry (O'Brien et al. 2004), giving the drug more time to find its target and often allowing for the use of lower doses. Longer circulation times are also generally associated with reduced toxicity to organs involved in drug excretion (e.g., the kidney and liver), because of slower accumulation in these organs and a lower maximum drug concentration at any given time.

A second advantage of nanoparticles, compared with small-molecule drugs, is that they do not freely perfuse all tissues but are confined to blood vessels and tissues with highly permeable vasculature (i.e., the liver, spleen, and tumor). This results in a lower chance of toxicity to healthy organs. The best known example is the drug Doxorubicin: its cardiotoxicity is reduced 7-fold when packaged in a nanoparticle (O'Brien et al. 2004).

Third, nanoparticles can be used to solubilize drugs that are highly hydrophobic and cannot otherwise be administered to patients, thus increasing the number of drug candidates.

Despite the clear advantages of nanoparticles, nanoparticle-based drug formulations have not consistently led to a significant improvement in patient survival compared with free drug. As a result, only six nanoparticles have FDA approval for the treatment of cancer (Ventola 2017). There seem to be two primary (and related) reasons for the limited efficacy of nanoparticles: low levels of accumulation in tumors and limited penetration into tumor tissues.

A survey of the literature from the past 10 years found that, despite extended circulation time, only 0.7 percent (median) of an administered nanoparticle dose is found in solid tumors (Wilhelm et al. 2016). The accumulation is largely driven by the enhanced permeability and retention associated with the greater vascular permeability of tumors and poor lymphatic drainage.

Nanoparticles are designed to be biocompatible so they do not elicit a significant immune response and biodegradable.

Once nanoparticles cross the vascular wall, they need to penetrate a dense extracellular matrix in order to reach tumor cells. Unfortunately, nanoparticles typically travel just tens of microns over the course of days (Sykes et al. 2014; Wang et al. 2015).

Theranostic Targeting

Strategies are being explored to improve both the accumulation and penetration of nanoparticles in tumors. The most common approach to bolster the accumulation of nanoparticles in tumors involves functionalizing the nanoparticle surface with targeting ligands specific for a tumor biomarker. While targeting alone does not address the challenge of tumor penetration, the penetration has been shown to increase with repeated dosing.

The benefits of targeting probably stem from better retention of the nanoparticles in the tumor rather than a greater quantity of nanoparticles that reach the tumor. Targeting also likely improves the probability of nanoparticle binding and internalization by cancer cells (in relation to surrounding stromal cells), which can enhance drug efficacy. Moreover, the targeting agent may exhibit an additive, or even synergistic, therapeutic effect on target cells when combined with the chemotherapeutic payload in the nanoparticle (Yang et al. 2007).

Challenges and Solutions for Targeting Strategies

While targeting is widely considered to be beneficial, studies have shown that receptor targeting does not always make therapeutic nanoparticles more efficacious (Lee et al. 2010; McNeeley et al. 2007). It is now understood that many complicating factors can limit the success of targeted nanoparticles. Not surprisingly, poor tissue penetration remains a significant problem. Heterogeneous antigen expression and/or the loss of cell surface antigen expression during disease progression are also problematic.

Use of the Tumor Microenvironment

One strategy being tested to overcome the high variability and instability of cancer cells involves taking advantage of cues in the tumor microenvironment to promote nanoparticle retention in tumors. For example, numerous nanoparticles have been developed to be retained in tumors in response to the acidic tumor microenvironment, matrix-metalloproteinases, hypoxia, binding of stromal cells, and other factors common to most tumor types (Du et al. 2015). A variation on this approach involves using biological cues to generate smaller nanoparticles in the tumor environment so that they can diffuse more readily through the interstitium (Li et al. 2016; Wong et al. 2011).

Progress toward personalized medicine is needed to determine which targeting strategies will be effective in individual patients.

While targeting strategies that take advantage of the tumor microenvironment have seemed encouraging in preclinical studies, no single approach can be used in all patients because of patient-to-patient variability. Progress toward personalized medicine is needed to determine which targeting strategies will be effective in individual patients.

External Stimuli

As an alternative to molecular and environmental signatures for targeting, externally administered stimuli have been used to improve the accumulation and penetration of nanoparticles. Pharmacological stimuli have included enzymes to degrade the extracellular matrix (Parodi et al. 2014), inhibitors to limit matrix generation (Diop-Frimpong et al. 2011), and drugs to alter vascular permeability or blood flow (Chauhan et al. 2012). Physical triggers include radiation (Baumann et al. 2013; Koukourakis et al. 2000) and ultrasound (Mullick Chowdhury et al. 2017; typically in combination with microbubbles). By increasing vascular and tumor permeability both approaches can dramatically improve nanoparticle delivery when timed appropriately.

Magnetic forces can also be used to boost the accumulation and penetration of nanoparticles in tumors. While this has been limited to superficial tissues (Al-Jamal et al. 2016; Schleich et al. 2014) because of the rapid dropoff of the magnetic field gradient with distance from the magnet, proper configuration of multiple magnets can enhance the delivery of magnetic nanoparticles into deep (permeable) tissues.

Physical triggers can also be used to promote the release of drugs from nanoparticles. The hypothesis is that once a drug is released it can more readily perfuse the tumor tissue. A second possibility is that the rapid release of a drug from intratumoral nanoparticles can yield a higher effective dose. Importantly, for this approach, drug release must be limited to the tumor and not be triggered in healthy organs. The most common physical trigger is light irradiation to promote drug release from light- or thermally responsive nanoparticles (Linsley and Wu 2017), but its use is limited to superficial tumors.

Recent work shows that alternating magnetic fields can be used to spatially target the heating of magnetic nanoparticles and trigger drug release from thermally responsive nanoparticles (Tay et al. 2018).

A limitation of all physical triggers is that their effect is confined to the primary tumor. The use of external triggers will therefore need to be complemented with biological targeting strategies to ensure the elimination of metastatic niches.

Prospects

As advances continue in nanoparticle design efforts to overcome the many challenges of treating cancer, there has been a corresponding increase in nanoparticle complexity and cost, and yet there are still very few examples of clinical benefit. Many failures stem from the inability to produce complex nanoparticles at large scale. Therefore, there seems to be movement toward simplifying nanoparticle designs to achieve high drug encapsulation efficiencies, high drug payloads, and high conjugation efficiencies with few (or no) purification steps required.

While progress toward effective treatments for cancer is taking longer than expected, researchers are beginning to understand the obstacles that have prevented nanoparticles from significantly reducing the cancer death rate. Innovative solutions are being identified that will one day allow nanoparticles to live up to the lofty expectations of them.

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Theranostics holds promise for achieving rationally designed immunotherapies that can harness the full potential of the immune system in treating disease.

Immune Theranostics

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As understanding improves about how the immune system functions, engineers can begin employing principles of rational design to modulate immune responses for therapeutic applications. Key tools in this frontier of immunoengineering have emerged from biomaterials and nanoscale science, such as theranostics: the combined delivery of therapeutic and diagnostic agents. By providing a means of tracking and quantifying cells that are targeted and modulated during vaccination and immunotherapy, theranostics makes it possible to approach the immune system less as a mysterious "black box" and more as an interlinked network of cells and signaling molecules that can be mapped for improved reproducibility and understanding. Immune theranostics holds promise for realizing technologies that harness the full potential of immunotherapy in the treatment of a wide range of inflammatory disorders.

Background

The immune system is a dynamic and highly responsive network of bioactive molecules, cells, and tissues. It must continuously maintain the homeostasis of its host body within a strict set of physicochemical boundaries while being ever ready to address an equally complex and evolving repertoire of invading pathogens and heterogeneous cancers. Adding to this complexity is the uniqueness of each patient's immune system—women, men, children, neonates, the elderly, and the diabetic can each have distinct immune responses to the same stimuli. Furthermore, prior exposure to particular inflammatory molecules and conditions, such as certain foods or regional infections, can have significant impacts, even preventing allergic reactions or making some vaccines ineffective in specific parts of the world.

Nanobiomaterials permit the design of materials to directly elicit therapeutically beneficial responses from the immune system.

While the protective abilities of the immune system have long been tapped for the generation of vaccines, its potential to be directed toward the treatment of cancer and inflammatory disorders has been explored only relatively recently in the form of immunotherapy. But what methods are available to controllably and reproducibly modulate this system, which varies from person to person and based on sex, age, and disease state? To address this need, immunoengineers apply principles of rational design, biomaterials science, nanoscale science, systems analysis, and numerous other engineering disciplines to better assess, control, and customize immune responses for safe and reproducible therapeutic applications.

A New Frontier for Engineering: Rational Immunomodulation

Immunoengineering is a relatively new field, but its concepts have always been a core component of biomaterials science. Materials development for biological implants and in vivo controlled delivery have historically focused on minimizing inflammation. Biomaterials are therefore usually optimized to inhibit the activation of inflammatory immune cell populations in tissues and biological fluids, to decrease toxicity, increase the therapeutic efficacy of delivered agents, and extend the lifetime of implanted devices.

Now, instead of a focus on preventing inflammation, advances in the development of nanoscale biomaterials (nanobiomaterials, NBMs[1]) permit the design of materials to directly elicit therapeutically beneficial responses from the immune system (Allen et al. 2016; Scott et al. 2017). The immune system interacts with NBMs based on a never-ending battle with viruses. Nanoscale lipid vesicles released by immune cells are essential components of cell-cell communication and signaling, and biomimicry of these nanostructures presents a pathway for probing, modulating, and monitoring immune responses.

With these developments theranostics—the combined delivery of *thera*peutic and diag*nostic* agents—has emerged as a vital tool for identifying and tracking immune cells that are modulated by delivered drugs and immunostimulants (Allen et al. 2018; Karabin et al. 2018). "Immunotheranostic" strategies are significantly enhancing the ability of engineers to reproducibly generate immune responses by monitoring which components are modulated at the organ and cellular level during immunotherapy and vaccination (Du et al. 2017, 2018).

Previous Methods of Vaccine Development: Treating the Immune System as a Black Box

Vaccination is fundamentally the process of training the immune system to recognize and eliminate pathogens either prophylactically or therapeutically and can thus be considered one of the first forms of immunotherapy. Although it may seem obvious that immunology should be a key component of vaccine design, this has not always been the case.

Rational vaccine design requires an understanding of the immune system that has not yet been achieved, but the urgency to aid the sick and prevent the spread of infection has presented no alternative other than the use of trial-and-error methods. As a result, most immunization strategies were developed by treating the immune system as a black box. Antigens (molecular components of pathogens) and adjuvants ("danger signals" that stimulate inflammatory cells) are randomly combined in formulations that serve as the input into the system. The output from the black box is the (hopefully) lasting and protective immune response. With little understanding of the mechanism by which antigens and adjuvants achieve this output, formulations are selected that generate the safest and most effective prevention or removal of infection, with lasting immunological memory to respond quickly to future pathogen exposure.

But complex cell-cell interactions occur and dozens of signaling molecules known as cytokines are released

[1] NBMS are broadly defined as any biomaterial with at least one external dimension that is less than 1,000 nm.

by inflammatory cells during an immunization. It is critical to know which cells contribute to these responses and whether the same cells can be reproducibly stimulated across different human populations. Importantly, different immune cells express different combinations of cytokines, often in amounts proportional to the extent of their exposure to the adjuvant, and this network of activated inflammatory cells and released cytokines forms an emergent system that can be tailored for specific therapeutic applications.

By employing targeted NBMs to control and monitor which immune cells are modulated during vaccination, theranostics provides a means to explore this black box to better correlate the input vaccine or immunomodulatory formulation with the output immune response.

Engineering Nanobiomaterials for Targeted Immunomodulation

NBMs are key tools in immunoengineering and have attracted much attention for their ability to deliver therapeutics and imaging agents to specific cells and tissues (Allen et al. 2016; Scott et al. 2017). This versatility has demonstrated improved efficacy and deployment of vaccine formulations by providing triggered or bioresponsive mechanisms for controlled release, transporting combinations of bioactives with diverse solubility, and allowing control over reproducibility, speed, and cost of production (Scott et al. 2017).

Among the range of available NBMs, self-assembled NBMs composed of synthetic amphiphilic polymers are especially advantageous for vaccination and immunotherapy because of their versatility in chemistry and structure (Allen et al. 2016). These traits allow better mimicry of viruses, which possess physicochemical and structural characteristics that dictate their interactions and processing by critical immune cells known as professional antigen presenting cells (APCs).

Professional APCs—which include dendritic cells, macrophages, and B cells—are the most frequent targets of immunomodulatory NBMs because of their potency for cytokine release and T cell activation. T cells are the effector cells of the immune system that can directly kill virus-infected or cancerous cells (cytotoxic T cells) as well as direct or enhance functions of other immune cells (helper T cells).

Using a military hierarchy as an analogy, T cells can be considered both soldiers and noncombat support troops while APCs are the generals that direct their action. NBMs function as a direct line of communication to the generals by alerting them of imminent danger (adjuvant) and identifying targets (antigen) for elimination. After internalization by APCs, NBMs are degraded in intracellular compartments that contain a variety of enzymes and redox mediators (Owens and Peppas 2006), allowing transported payloads to modulate APC function for the activation of T cells.

Theranostics as a Tool to Improve Vaccine Design and Reproducibility

Continued progress in theranostics will allow early detection of disease, prevent unintended side effects of drugs, decrease the frequency and amount of administered drugs, and allow quantitative assessment of the accuracy of drug delivery in individual patients. Immunotheranostic nanomedicine may thus revolutionize treatments for numerous inflammatory disorders, including cancer and heart disease, by providing powerful new approaches not only for therapeutic delivery and diagnosis but also for personalized medicine and clinically relevant assessment of therapeutic efficacy.

NBMs are key immunoengineering tools because they can deliver therapeutics and imaging agents to specific cells and tissues.

Using viruses, bacteria, and other pathogens as inspiration, biomimetic NBMs can be engineered with physiochemical properties selected to stimulate or suppress specific APC populations while marking them for detection and quantification via multiple diagnostic modalities. As an example, theranostic delivery of a drug regimen to reduce vascular inflammation in patients with cardiovascular disease could allow a clinician to monitor the patient's progress during treatment. Since not all patients will have the same response to anti-inflammatory drugs, the clinician could adjust the treatment as necessary by monitoring the levels of critical inflammatory cells in the patient's arteries. NBMs targeting dendritic cells may serve such a function, as the level of these APCs in vascular lesions directly correlates with the risk of rupture and vascular occlusion (Bobryshev 2010). There is currently no noninvasive method to detect such unstable lesions in patients, many of whom could suffer heart attack or stroke without warning.

Engineering NBMs for Use with Diagnostic Imaging

NBMs can be engineered to be amenable to a variety of diagnostic methods depending on the specific need. Commonly employed imaging modalities include single-photon emission computed tomography (SPECT/CT), positron emission tomography (PET), magnetic resonance imaging (MRI), and fluorescence/luminescence spectroscopy. MRI stands out for safety during repeated use, in contrast to techniques requiring high doses of radiation like SPECT/CT and PET. PET has superior spatial resolution (4–5 mm) to SPECT (10–15 mm) and high sensitivity that can detect picomolar tracer concentrations. Although lower resolution than PET, MRI enhanced with contrast agents (e.g., gadolinium-conjugated NBMs and superparamagnetic iron oxide nanoparticles) can be used to characterize various features of targeted tissues.

Immunotheranostic nanomedicine may revolutionize treatments for cancer and heart disease with new approaches for drug delivery and diagnosis.

While fluorescence is impractical for clinical applications because of poor tissue penetration, it enables unprecedented quantitative analysis of cellular targeting in animal models, where organs and cells can be extracted for analysis by flow cytometry. This immunotheranostic strategy significantly enhances the ability to reproducibly elicit immune responses by monitoring which components are modulated at the cellular level during the development of vaccines and immunotherapies (Dowling et al. 2017).

Conclusions and Future Directions

Theranostic NBMs hold great promise for diagnostic imaging and controlled delivery of therapeutics during immunotherapy, providing a much-needed method for mapping and understanding the complex network of inflammatory cells that contribute to elicited immune responses.

The immediate future directions of theranostics will likely focus on two critical issues. First, APCs will nonspecifically remove NBMs from circulation regardless of surface-conjugated targeting moieties like antibodies and peptides, making selective APC targeting difficult to achieve. Avoiding uptake by off-target APC populations will require more advanced engineering of the nano/biointerface, such as precisely controlling the surface density and affinity of multiple targeting moieties (Nel et al. 2009), incorporating inhibitory signals like the CD47 ("don't eat me") peptide (Rodriguez et al. 2013), and optimizing NBM structure and size (Yi et al. 2016).

Second, the scalable self-assembly of monodisperse NBMs that mimic the complex nanoarchitectures of viruses remains a challenge. Current methods usually involve impractically complex polymers, low yield of the desired nanostructure, and difficulty with therapeutic loading, particularly dual loading of hydrophobic imaging agents and structurally sensitive water-soluble biologics. Recent advances in the commercially scalable technique of flash nanoprecipitation have demonstrated the scalable assembly of complex self-assembled NBMs from poly(ethylene glycol)-*bl*-poly(propylene sulfide) amphiphilic block copolymers (Allen et al. 2017). This method of impinging organic and aqueous phases in confined impingement jet mixers achieves highly reproducible and customizable nanoprecipitation conditions for the fabrication of polymersomes and bicontinuous nanospheres (Allen et al. 2018; Bobbala et al. 2018), which are unique NBMs capable of transporting lipophilic and water-soluble payloads simultaneously.

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Political, scientific, business, and social institutions rely on voting methods that appear to fail on important human factors.

Human Factors of Democracy

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Voting is a powerful instrument in the civic arsenal. The ballot is mightier than the bullet, Abraham Lincoln once observed, and Theodore Roosevelt likened votes to rifles. Individual expressions are transformed to public choices, thus "poll-vaulting" the fates and futures of societies. Taxpayers vote for their representatives in government. Shareholders vote for directors to oversee the business of corporations. People vote to decide who joins a club, who leads religious and social organizations, or what investments an association should make. Ubiquitous social media amplify the importance of judicious voting.

Society's collective choices also shape the conduct and impact of the sciences and the development of related policies. Because the economic consequences and public accountability of science policy are often high and funds are limited, decisions almost always require priority setting. For example, public and private funds are typically granted for research after a competitive evaluation and scoring of proposals. Scientific prizes, medals, and honor society memberships are awarded based on committee decisions. Public health recommendations, weapons acquisition options, missions for space exploration, trade treaties, university rankings, and hiring decisions at

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all levels also rely on various choice mechanisms. All of these scenarios involve some form of voting to determine the outcome.

But different rules yield different results for the same choices available to voters.

Inconsistent "Rules" of Voting

The related literature on social choice has two "truths": first, no voting rule is perfect (Arrow 1950; Balinski and Laraki 2011; Sen 2017); second, all known methods can be manipulated by strategic (versus sincere) voting (Gibbard 1973; Satterthwaite 1975). In addition, voting methods are poorly understood and often obscure (sometimes perhaps deliberately so). They vary greatly in comprehensibility, ease of use, and voters' ability to express themselves, all of which can influence voter participation (Madhavan et al. 2017). Yet very few organizations give even momentary thought to their voting methods and their relevance.

The widely used *Robert's Rules of Order* strives to bring all complex decisions down to pairwise choices. As is well understood, numerous opportunities exist in this approach to predetermine outcomes. But when voters confront three or more options, voting becomes much more complicated, and attempts to simplify to a sequence of pairwise votes are rife with hazards.

Here, as is typically done in engineering design, testing, and refinement of products (Madhavan 2015; Norman 2013), we consider human factors to better understand the meaningfulness of voting methods from a user's standpoint.

Choosing How to Choose

A principal challenge emerges from collective choices when more than two options exist. This relates to the impossibility of finding a voting rule that satisfies seemingly simple requirements, such as fairness, universality, efficiency, and no change in other pairwise rankings when a candidate is added or removed (Arrow 1950; Balinski and Laraki 2011).

Six Approaches to Selection

Most approaches use voters' ranked (ordinal) preferences as the basic input, but other options include the following:

- *Vote for one:* the winner either obtains a plurality of the votes cast or is determined by a runoff (this is the most commonly used tool worldwide).
- *Approval voting:* voters vote for each candidate they endorse (i.e., anything from none to all of the choices); the priority order is determined by total approvals.
- *Rank order lists:* voters individually produce ranked lists that can be combined through many approaches, each of which may yield different voting results.
- *Dotmocracy:* voters distribute, say, 20 or 100 points across available candidates, with ranks determined by the sum of allocated points.
- *Range voting:* voters assign a score from 0 to 99 to each candidate, with ranks determined by sums of scores.
- *Majority judgment:* voters categorically grade each candidate using a standard vocabulary, as in academic grading (A = "excellent," B = "very good,"… F = "unacceptable"); median values are used for final scores with lexicographic rules for breaking ties.

It is not always clear, however, that the scoring or ranking inputs have the same meaning for each voter. Without this, aggregating them has no meaning.

Assessing Selection Methods

Most research on social choice presumes that a vote represents a statement of the satisfaction of the voter if different candidates win, and hence (following a long tradition in economics) limit such representations to ordinal rankings (Arrow 1950; Balinski and Laraki 2011).

Voting methods vary in comprehensibility, ease of use, and voters' ability to express themselves, all of which can influence voter participation.

In sharp contrast, majority judgment specifies a common language (words such as excellent, very good, good, fair, poor, unacceptable) that voters use to grade candidates. There is no reference to the satisfaction of the voter, but rather their measure of the merits of the

TABLE 1 Voting inputs and possible expressions

	Number of expressions	Number of expressions with K=6 candidates
Vote for one	K	6
Approval voting	2^K	64
Ranking	K!	720
Dotmocracy (for M points) For 20 points assigned	M!/[K!*(M–K)!]	38,760
Range voting (for M points) For 20-point scales	M^K	64 million
Majority judgment For N=6 grades Using +/– modifiers, N=21 grades	N^K	46,656 >34 million

Note: For 100-point scales, dotmocracy and range voting expressions exceed 1 billion.

candidates. Range voting seems to have a similar structure and, indeed, assumes that the 0–99 score range has a common meaning to all voters; however, this has not been tested, and is almost certainly invalid. Similarly, "approval voting" implicitly assumes that "approve" has the same meaning for each voter—also an untested presumption.

Another important human factor concerns the richness of vocabulary that each method offers voters to express themselves, varying from minimal expressiveness to millions of "words." Table 1 shows the number of expressions available using various methods for *K* candidates.

The standard US voting method—pick one candidate—has the least possible expressiveness. Approval voting is next to last, but notably better. Widely used rank-order lists have a richer vocabulary, but ranking limits the extent of expression since ties are typically not allowed and the gaps between ranks are not revealed; for example, candidates ranked 1 and 2 might be very close together or far apart—the information is masked by the rank order. Grading methods (majority judgment) and point spread methods (dotmocracy) offer far richer vocabularies, and point scoring methods (range voting) offer nearly endless expressions. But it is not known how much these matter to the real electorate.

It is important to consider how comprehensible various methods are to the general voter. Among the few merits of the US system, most voters can easily describe the standard voting processes (majority, plurality, or runoff election), but few likely understand the full consequences of their use. At the other extreme, some proposed voting methods require advanced mathematics to explain. Since two thirds of US adults have at most a high school education, it is unlikely that they can understand voting methods that require higher-level mathematics, and voters are likely not to trust or participate in elections using voting methods that they do not understand.

Standard methods for evaluating voting rules test them against a set of criteria. A voting method fails if any distribution of votes creates a violation of the criteria (Balinski and Laraki 2011), but many of these mathematical violations rapidly diminish or disappear as the number of voters increases. A human factors approach considers how often and under what circumstances violations occur, rather than simply demonstrating the possibility of a violation.

The Human Element: Examples of Impacts

An Exercise in Funding Prioritization

In what we believe is unique for this line of inquiry, in a small study we asked respondents to evaluate a set of choices that were professionally relevant to them using six different voting methods. We compared the results, focusing on how the participants evaluated the voting methods.

Our 21 respondents were scholars and professionals attending our symposium at an international conference on health outcomes research and technology assessment.[1] We asked them to act as advisors to a national health system and to choose from the fol-

[1] The 20th Annual European Congress of the International Society for Pharmaceutical Outcomes and Research, Glasgow, November 4–8, 2017. The focus of the conference was the evolution of value in health care.

lowing six options for investing public funds: (1) new medical imaging capability (MRI, CT, PET scanners); (2) intensified research on a drug to delay the onset of Alzheimer's disease; (3) interventions to reduce obesity and smoking; (4) development, testing, and transition to market of a gene-based therapy for Huntington's disease (which affects 1 per 10,000 people); (5) accelerated research and development on a vaccine to prevent Ebola; and (6) increased hiring and improved retention of clinicians and nurses (by 10 percent) to enhance everybody's access to care.

Although synthetic, these options reflected real-world constraints and were accompanied by an estimate (from 20 to 55 percent) of available funds that would be consumed by a given option. Participants were told that available funds would cover only a portion of the choices—and would consume 150 to 220 percent of the available budget if all were attempted—so prioritization was essential. The six voting methods tested—vote for one, approval voting, rank order, dotmocracy, range voting, and majority judgment (allowing + or – designations to letter grades but not requiring them)—were described in detail; some were familiar to the participants, others novel.

The results confirmed that different voting methods create different priority lists when used by the same people. All six voting methods selected the same two options as the least favorite (a cure for Huntington's and a vaccine for Ebola), but they differed considerably in prioritizing the remaining four, so each method would lead to different funding decisions if actually employed in practice. Two of the methods—vote for one and range voting—appeared to produce more outlier results than the other four methods.

Of more interest and consequence are the participants' feedback on the voting methods themselves. We asked them to evaluate the methods on four dimensions: (1) ease of use, (2) expressiveness, (3) enjoyableness, and (d) likelihood of future use in professional settings. The results of our preliminary data are telling. Of the 21 participants, 15 disliked (on several dimensions) the vote for one method and, considerably more than any other option, would prefer not to use it in the future. With less unanimity, participants found majority judgment and dotmocracy the most expressive and to some extent the most enjoyable. They moderately preferred rank ordering for future use, noting its ease of use, which their comments indicated was due to their greater familiarity with the method.

Many of our participants had never encountered approval voting, range voting, dotmocracy, or majority judgment. Perhaps with more familiarity and experience people might actually prefer dotmocracy or majority judgment, the methods our participants often identified as most expressive and enjoyable for use.

> *Different voting methods can actually lead to different funding decisions.*

Honorific Society Election Processes

In addition to this experiment, we reviewed the member election processes of leading honorific societies as described on their websites, including procedures for selecting Nobel prizewinners. We observed two distinct features of the selection processes:

- They invariably involve an initial narrowing of the candidate pool in several steps—none of which are clearly described and all of which appear to involve considerable subjectivity.
- They commonly involve a final majority vote on the candidates by a defined body of voters, but nothing describes what they actually vote on. It may be an approval voting process (which could lead to multiple winners, as commonly occurs with the Nobel prizes), or approval of a slate created by a committee, or some other mechanism.

These preliminary steps of "elimination"—also common in the review of grant proposals—require further scrutiny to fully understand how important scientific funding decisions are made.

Making the Right Choice

A question that animates the scientific community is how to improve the selection processes that lead to federal and other grant awards. Since divergent views and disagreements cannot be eliminated, it is necessary to determine how best to consolidate the differing opinions of reviewers and decision makers into meaningful group choices.

First, reviewers need a common language to describe their views. While some may believe that numeric scoring systems provide this language, such systems can mean quite different things to different reviewers. For instance, does a score of 1 (or 9) on a scale mean the best (or worst) of the current group of proposals, or proposals that reviewers have ever seen, or that they can imagine? Some may even confuse whether 1 or 9 is best. If reviewers apply different meanings for these scores, averaging them has no more meaning than averaging Fahrenheit and Celsius temperature readings.

If reviewers apply different meanings for scores, averaging them has no more meaning than averaging Fahrenheit and Celsius temperature readings.

Strategic manipulation is another source of incongruity: reviewers shift scores depending on how various proposals relate to their own (preferred) line of research or worldview. This practice has been extensively analyzed in the scoring of athletic events (such as figure skating and gymnastics) that, analogous to scientific reviews, requires subjective judgment (Balinski and Laraki 2011). The opportunity for strategic manipulation looms large in competitive grant review processes, even with blinded reviews.

Ultimately the only way to assess the value of various voting methods is to test them head-to-head in various voting situations. Only with such direct comparisons is it possible to ascertain how often the methods agree or disagree in rankings and resulting decisions, which seem better suited to various settings, and which create the greatest sense of trust among the participants.

Vox Populi

Political, scientific, business, and social institutions rely on voting methods that appear to fail on important human factor dimensions. The most widely used method—voting for one candidate—is the most constraining, offers the lowest possible expressiveness, is the least informative, and was the most disliked by our respondents.

Although more experiments and field testing are necessary to develop this area of research, it would be beneficial to improve public familiarity—and comfort level—with diverse voting methods and how they affect outcomes across settings. The use of tools of engineering design can not only enable more expressive public opinion for important decisions but also lead the way toward scientifically informed choice systems, thereby improving public policy decisions and, ultimately, democracy.

Acknowledgment

We are grateful to Cameron Fletcher, whose comments and feedback improved this article.

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The vision, concept, and framework of socially responsible automation can help technologists and business leaders drive the evolution of automation for societal good.

Socially Responsible Automation:
A Framework for Shaping the Future

Meera Sampath and
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Socially responsible automation (SRA) is a vision, concept, and framework to address the strong need to shape the future development of automation to help create a better world for people and society.

The past few decades have witnessed significant strides in the adoption and proliferation of automation spurred by technological advances in computing, sensing, networking, and communications. Breakthroughs in artificial intelligence (AI) and machine learning, which may currently be the most important general-purpose technologies (Brynjolfsson and McAfee 2017), have broadened the scope of automation beyond mechanized labor and industrial robotics to knowledge work and cognitive agents. Machines increasingly not only perform repetitive, routine tasks in predictable environments but also are being deployed to make complex judgments and solve problems that typically require human intelligence and understanding.

Background

Manufacturing automation, in particular, has significantly affected the employment, productivity, and economic performance of companies and nations. As automation begins to impact knowledge work and the servic-

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es sector, effects on the global workforce will be even more profound. Although, given the many comparative advantages that humans have, the scope of full substitution of human jobs by automation is likely to remain bounded, at least for the foreseeable future (Atkinson 2017; Autor 2015; Bughin et al. 2017), worker displacement, demand for newer skills, and the continued evolution of work-supplying organizations are inevitable as automation technology develops.

Predominantly cost-based automation programs often fail to deliver, are unsustainable, or even end up being detrimental to business interests.

A recent report from the National Academies of Sciences, Engineering, and Medicine (NASEM 2017) discusses in depth the impact of information technology (IT) and automation on the US workforce. While automation, in conjunction with globalization, trade, and economic policies, has been a strong contributing factor to lower employment ratios and increased income inequalities over the past few decades, it is not just the technologies themselves but the choices made around them that have driven these impacts. Noting, for example, that advances in internet and communication technologies paved the way, in a manner unforeseen, for the outsourcing and offshoring of business work, the report notes that organizational decisions, power structures, and ideologies ultimately shape the outcomes of technologies for the workforce, society, and economy. And "technologists, policymakers (such as private-sector managers and public officials), and other leaders have the power to design IT and deploy it for the benefit of society, driven by a broad discussion of what impacts are desirable and a deeper understanding of how design, deployment, and policy decisions can achieve these impacts" (NASEM 2017, p. 138).

Similar sentiments are echoed in a report of the IEEE (2016) Global Initiative for Ethical Considerations in Artificial Intelligence and Autonomous Systems. Citing the technology community's lack of awareness and ownership of socioeconomic concerns surrounding automation, the report urges all those "involved in the research, design, manufacture, or messaging" of autonomous systems and AI to go beyond the search for more computational power or the attainment of purely functional goals and technical solutions (IEEE 2016, p. 3). It calls on them to place human well-being, empowerment, and prosperity at the core of their pursuits, and to ensure that technology choices are "thoroughly scrutinized for social costs and advantages that will also increase economic value for organizations by embedding human values in design" (IEEE 2016, p. 36).

Socially Responsible Automation (SRA): Four-Level Model

Motivated by the above considerations, we introduce the vision, concept, and framework of socially responsible automation to help technologists and business leaders drive the evolution of automation for societal good. This aspirational vision is grounded on two principles:

1. humans will and should remain critical and central to the workplace of the future, controlling, complementing, and augmenting the strengths of technological solutions; and
2. automation, artificial intelligence, and related technologies are but tools to improve and enrich human lives and livelihoods.

Our definition of automation encompasses mechanized physical labor as well as information-based cognitive work ("knowledge work") and combinations of these. Also, while the term "human-centric" (or "human-centered") automation has been used by some researchers (e.g., Oishi et al. 2016) in the context of safety and efficiency of human-technology interaction in semiautonomous systems, we use human-centric to refer to approaches that broadly support the professional, social, and economic well-being of humans in a world of ubiquitous automation.

We define, describe, and illustrate the SRA vision using a four-level conceptual model that captures current industry practices as well as envisioned future approaches to automation. The SRA pyramid (figure 1) provides a simple but powerful visual aid for guiding automation strategy development.

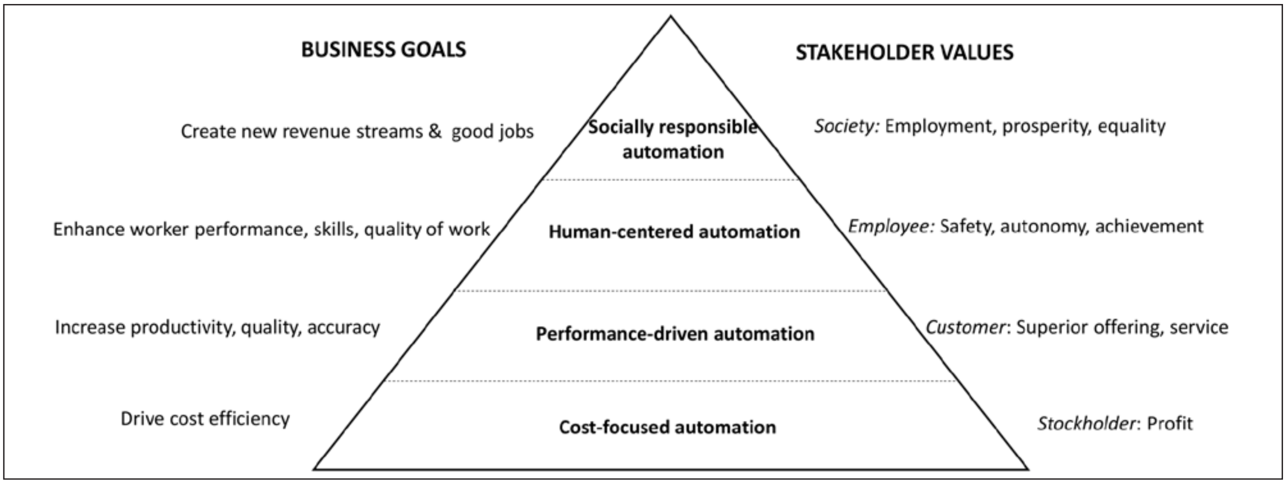

FIGURE 1 The socially responsible automation (SRA) pyramid captures four levels of automation, each with a distinct business goal and set of stakeholder values, leading to socially responsible automation practices at the highest level that can support both business growth and societal good.

Level 0: Cost-Focused Automation

At the lowest level of the model are approaches to automation that are predominantly cost-focused: economic benefits from labor reduction drive technology decisions. Such cost-based programs are not only not socially conscious or human-centric, they also often fail to deliver, are unsustainable, or even end up being detrimental to business interests.

Consider, for example, the business process outsourcing (BPO) industry whose core business model is based on labor arbitrage and the availability of inexpensive human capital in developing countries. Rising costs of doing business in once preferred destinations such as India and China have driven increasing interest in new technologies such as robotic process automation (RPA), the use of software "bots" (IRPAAI 2015) for repetitive, high-volume tasks. Considered a disruptive trend, RPA holds tremendous promise for the BPO industry. However, success has so far been limited (Edlich and Sohoni 2017; Rutaganda et al. 2017) in part because of (1) a piecemeal approach to automation that fails to address systemwide implications and outcomes; (2) failure to account for the subtle but vital roles of humans in handling complex, nonstandard, and changing situations; and (3) the (hidden) costs of automation itself.

Level 1: Performance-Driven Automation

At the next level of automation, productivity and other performance metrics such as accuracy, scalability, speed, quality of service, and flexibility drive design and technology choices. Performance-focused approaches address several of the shortcomings of Level 0 automation by taking an end-to-end system view that is cognizant of the role of the human in the loop. Processes and systems are reengineered to take advantage of the benefits of automation while leveraging human skills and capabilities to supplement and overcome the limitations of technological solutions.

As an example, consider the retail giant Amazon's judicious integration of human and machine skills in its warehouses, where employees "pick, pack, and stow" goods while robots handle the transportation of loaded bins and shelves. Thus, robots do the routine tasks and "heavy lifting" that they are best suited for and humans perform tasks that require dexterity and flexibility that robots cannot yet do. This large-scale automation is reported to have resulted in significant reductions in "click to ship" cycle times and operating costs (Wingfield 2017).

Level 1 automation approaches move beyond cost efficiencies, but they are still driven primarily by business metrics without taking account of workforce implications or the societal costs and benefits of technology.

Level 2: Human (Worker)-Centered Automation

Human-centered automation approaches explicitly acknowledge and emphasize the critical and valuable role of people in human-machine cooperative systems. They are based on the idea that the ultimate goal of automation is not to sideline people or replace them with machines but to encourage new forms of human-technology interaction, augment human capabilities, and create new roles for people. The business goals are not just performance optimization but also worker development and enrichment. In comparison to the previous two levels, Level 2 automation is not technology-centric but, as the term makes clear, worker-centric. It is the first step in socially responsible automation practices.

Toyota exemplifies the adoption of human-centric automation practices with its philosophy that "robots are not the strategic centerpiece, but merely enablers and handmaidens, helping assemblers do their jobs better, stimulating employee innovation and when possible facilitating cost gains" (Rothfeder 2017). On Toyota's manufacturing lines, workers don't just troubleshoot and fix problems; they produce goods manually first, then continually innovate and simplify processes; once they perfect a process, the machines take over. In some cases Toyota has even eliminated automation so that workers retain their core expertise and skills and remain cognizant of the criticality of their roles in the company's mission.

Human-centered automation approaches encourage new forms of human-technology interaction, augment human capabilities, and create new roles for people.

Far from considering human workers as an expense to be avoided, Level 2 approaches leverage human capabilities to derive more business benefits in a manner that is workforce empowering. However, strategies and choices are still viewed within the sphere of the organization and not those of the broader business-society ecosystem.

Level 3: Socially Responsible Automation

At the highest level of the model is SRA: the technology choices, business strategies, innovation approaches, and management practices that move the affordances of automation beyond cost and performance efficiencies toward profitable and sustainable growth, with more and better jobs driving economic development and social cohesion. Thus, SRA centers on two core goals: driving growth through automation while promoting both economic performance and societal well-being.

Automation is inherently labor-reducing: "the structural dynamics of the economic system inevitably tend to generate what has rightly been called *technological* unemployment. At the same time, the very same structural dynamics produce counter-balancing movements which are capable of bringing the macroeconomic condition [of full employment] toward fulfilment, *but not automatically*" (Pasinetti 1981, p. 90; emphasis in original). While productivity gains from automation may lead to increased demand for a company's goods and services—increasing, in turn, the demand for labor—such outcomes occur only under the right conditions of labor supply, income levels, and demand for goods (Autor 2015).

Realizing the goals of SRA therefore will require explicit, active interventions, such as economic policies (Pluess 2015), and/or, as we suggest, simultaneously exercising the twin levers of automation and innovation. In other words, proactive, conscientious, and systematic identification of opportunities for new revenue streams and job-enabling growth should be an integral part of a business's automation strategy while leveraging the cost efficiencies and operational enhancements that automation provides.

Toyota is a great example, not just for human-centric automation but also for its SRA practices. The company's sustained growth and competitive positioning as an industry leader are the result of a judicious combination of the use of automation, innovation, and sound management practices. Toyota's strategy does not primarily target labor to reduce production expenses but instead is based on the smart use of materials, the design of parts to maximize performance and fuel efficiency, a platform-based approach for more economical global sharing of engine and vehicle models, and emphasis on lean processes that enable zero-downtime flexible manufacturing. With these measures, the company has continued to enjoy the top spot in sales and industry profit margins through the years, along with an expanding global workforce (Rothfeder 2017).

The next example is one that has become a poster child for the success of small business manufacturing in the automation era (Fishman 2013). Faced with declining demand for its products and rising competition, Marlin Steel, once the "king of the bagel baskets," reinvented itself through a series of remarkable measures. It made significant forward-looking investments in robotics and automation; reengineered its production processes; enhanced its product line to manufacture high-value, highly engineered custom metal wire products; and expanded its client base to new markets and customers. In addition to these structural measures, it invested in its people, equipping them with the skills and training necessary to survive and grow in the new technology-driven workplace. By taking this innovation-driven, business-focused, human-centric, and responsible approach to automation, Marlin Steel has grown in its revenue, competitiveness, and employee base.

Our four-level construct may remind the reader of Carroll's (2016) pyramid, the well-known model of corporate social responsibility (CSR). Indeed, our aspirational view of SRA is guided by the literature on CSR, a rich and mature field with theoretical underpinnings in the disciplines of business ethics, economics, and moral philosophy (Godfrey and Hatch 2007). In particular, we believe that SRA aligns best with the stakeholder theory of CSR. We also note the connection between SRA and ethical AI, which addresses a broader set of values (e.g., human rights, fairness, bias, transparency, and privacy; IEEE 2016) beyond the labor and workforce implications that are our focus in this paper.

Realizing the SRA Vision

Realizing the goals of SRA requires an organization's development and implementation, at many levels, of robust business, innovation, design, and technology strategies that are all aligned with and reinforce each other (figure 2). Drawing from a variety of disciplines—business ethics, innovation management, and socio-technical systems design—we highlight below selected frameworks and methodologies relevant to each of these strategic planks.

Business (Ethics) Strategy

A high-level business strategy for SRA begins with the question, "How can we fuel growth and enable job creation through automation?" To move automation beyond cost and performance efficiencies toward profitable, sustainable business growth with more and better jobs, the SRA approach identifies ways to (1) align a firm's commercial interests with societal values and (2) make social goals integral to an organization's core business model.

In a highly cited *Harvard Business Review* article, Porter and Kramer (2011) propose the principle of shared value: the idea of creating economic value in a way that also creates value for society. In this view societal needs, not just traditional economic needs, define markets, and the purpose of a corporation is to create shared value, not just profits. Companies that better connect their success with societal improvement open new avenues for innovation, new products, and new customers, all of which expand markets, create differentiation, and drive economic value and growth.

SRA can be thought of as an instantiation of the shared value concept in the context of automation. In this case, the shared value principle would guide firms to ask the following questions:

- How can we leverage the efficiencies gained by automation to tap into newer markets, revenue streams, and customers?
- How do we identify, enhance, channel, and leverage the critical value, both hidden and transparent, that our workers provide?
- How will specific technology choices affect employment and the societies where we operate?
- If economic efficiencies of technologies are comparable, which would have the least negative social impact, and which would maximize community benefit?

Our thinking on SRA is also influenced by the "common good" principle in ethics (Velasquez et al. 1992). With roots in the writings of

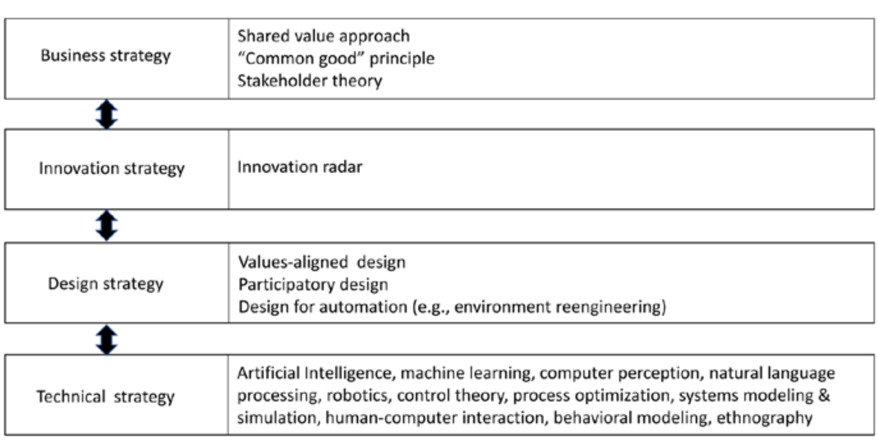

FIGURE 2 Socially responsible automation requires robust and mutually reinforcing business, innovation, design, and technology strategies. A few key frameworks and methods are illustrated here.

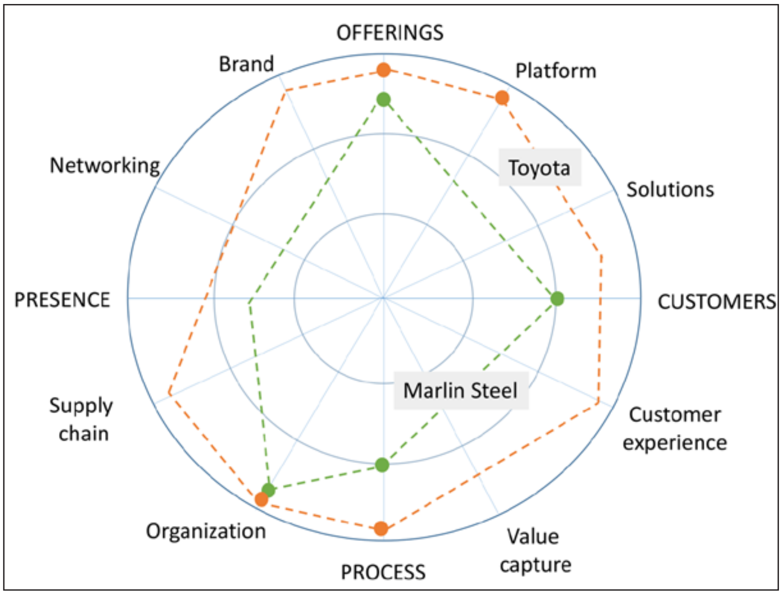

FIGURE 3 Innovation radars (based on the framework of Sawhney et al. 2006) illustrating the multidimensional innovation profile of two companies, Toyota and Marlin Steel, that exemplify socially responsible automation. The radars highlight the critical elements of their automation-based growth strategies. The *process* dimension incorporates the adoption of automation and the *organization* dimension captures the companies' human-centric focus.

philosophers such as Plato, Aristotle, and Cicero, a contemporary definition of common good comes from the political and moral philosopher John Rawls (1999, p. 233): "maintaining conditions and achieving objectives that are similarly to everyone's advantage." While not without its challenges (Velasquez et al. 1992), the common good principle not only provides a framework for technologists to consider the values supported—or compromised—by their choices but also helps them formulate and articulate the rationale for their decisions, which is key for stakeholder transparency (IEEE 2016). For other ethics-based approaches that may be more suitable for specific organizations and situations of automation deployment, we refer the reader to Velasquez and colleagues (2009).

Innovation Strategy

Driven by and closely aligned with a firm's business strategy are its innovation goals. Sustained job creation, at the heart of SRA, requires innovations of many kinds beyond the commonly recognized forms of product and process innovations. Sawhney and colleagues (2006) identify 12 ways for companies to innovate, with concrete examples of successful innovation strategies that leverage more than one and often several of these dimensions. The 12 categories for innovation are anchored by offerings, customers, processes, and presence (the who, what, how, and where of the business), supplemented by platform, solutions, customer experience, value capture, organization, supply chain, networking, and brand.

Both Marlin Steel and Toyota leverage innovations in product, process, and organization (i.e., changing a firm's form, function, or activity scope, including employee roles and responsibilities) as part of their growth strategy. We note further Marlin Steel's successful use of customer innovation (discovering new customer segments) and Toyota's platform innovation (using common components or building blocks to create derivative offerings), all alongside their core automation efforts. Figure 3 provides an illustrative representation of the multidimensional innovation profile of these two companies using the innovation radar devised by Sawhney and colleagues (2006).[1]

Finally, we note that in this era of digitalization and the fourth industrial revolution, automation has even stronger potential to drive growth by enabling smart products and smart services.

Design Strategy

Key to developing and implementing a robust SRA program is a broad systems design perspective. As depicted in figure 4, the "system" scope progressively expands at higher levels of the pyramid, from the physical and software infrastructures to human-technology integrated work environments to the business and social ecosystems supported and impacted by the technology. This calls for suitable systems design philosophies and approaches, two of which we highlight here.

Value-sensitive design (VSD), a concept that originated in computer ethics, "is a theoretically grounded approach to the design of technology that accounts for human values in a principled and comprehensive

[1] The radars in figure 3 are not based on a rigorous assessment of the two companies and are to be interpreted as qualitative representations of their innovation strategies.

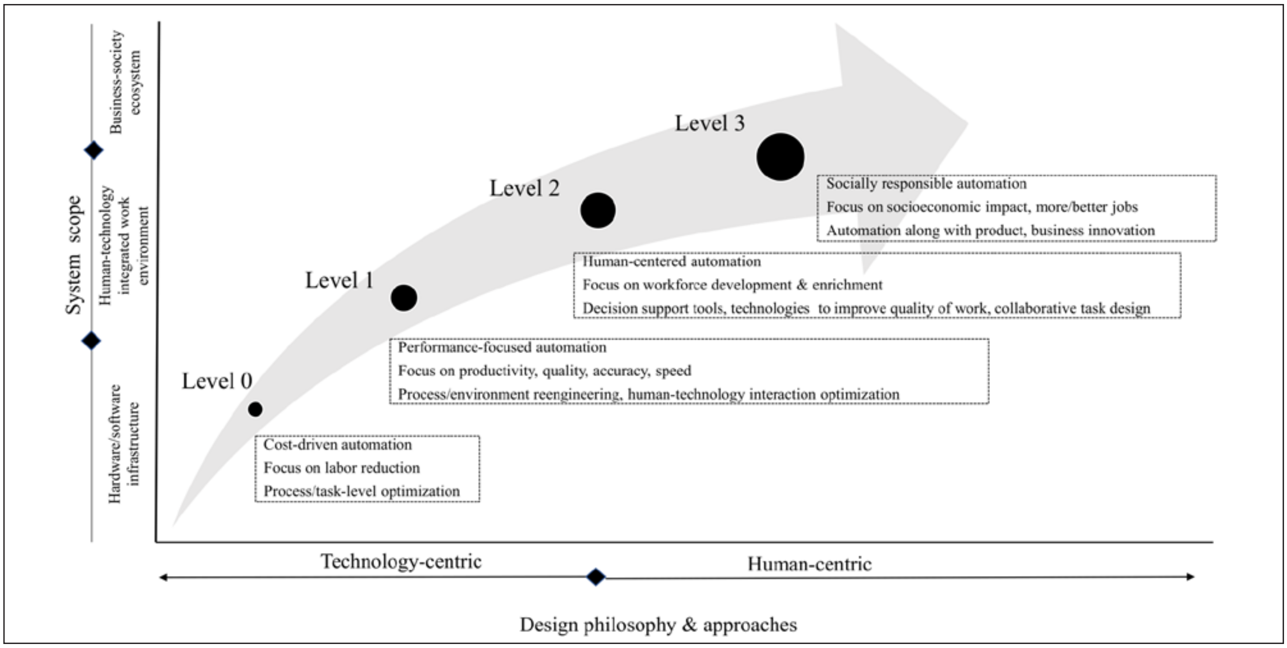

FIGURE 4 SRA requires a systems design approach. The progressively increasing system scope through the four levels of automation and the priorities at each level call for different design philosophies and design approaches that are technology- and/or human-centric.

manner throughout the design process" (Friedman et al. 2008, p. 70). VSD is an iterative approach that involves identifying stakeholders affected by the technology; understanding their views, preferences, and behaviors through quantitative and qualitative social science methods; and studying how specific technologies in specific contexts support or harm human values.

Another powerful systems design approach for automation is what Autor (2015, p. 23) characterizes as environment reengineering, the process of "radically simplify[ing] the environment in which machines work to enable autonomous operation." The "design for automation" philosophy is exemplified by Amazon's retail automation, robotic surgeries, and business process reengineering (Hammer 1990) in the services industry, where workflows and environments are redesigned to optimally leverage the complementary skills of robots and humans.

Technology Strategy

We highlight here some research challenges broadly categorized under human-technology cooperative work and integrated design tools and environments to support socioeconomically optimal technology choices for automation.[2] The first category concerns problems primarily at the intersection of control theory and cognitive sciences; these include optimal task allocation between humans and automated processes, real-time feedback control and adaptation in a cyber-human shared governance model, fail-safe operation of semiautonomous systems, and adaptive software systems for work automation. A quick scan of relevant literature indicates that many of these problems are beginning to be addressed in various technical communities.[3]

For integrated design tools, we believe that frameworks such as the Digital Twin that enable modeling, analysis, and evaluation of design choices in the manufacturing domain can be effectively extended to support both the design of human-technology collaborative environments and the evaluation of technology alternatives. However, significant work remains to be

[2] For an excellent overview of fundamental technologies and advances driving the proliferation of autonomous and intelligent systems, see NASEM (2017) and references therein. Brynjolfsson and McAfee (2017) provide a balanced review of the capabilities and limitations of current technologies.

[3] For example, the "future of work at the human-technology frontier" is one of the National Science Foundation's 10 Big Ideas (https://www.nsf.gov/news/special_reports/big_ideas/human_tech.jsp).

done to include rich human behavior modeling, worker performance modeling, and socioeconomic analysis in this framework. To the best of our knowledge, no such integrated paradigms exist outside the manufacturing domain for knowledge work automation.

Conclusion

As Rotman (2017) writes, "The economic anxiety over AI and automation is real and shouldn't be dismissed. But there is no reversing technological progress." The key is to implement measures that enable everybody to benefit from these transformative technologies and turn AI and automation into forces for shared prosperity.

In this paper we aim to help technologists and business leaders realize this vision by providing a comprehensive framework that looks beyond today's prevailing practices and provides a systematic, structured way to frame choices, assign priorities, and design robust strategies. We also discuss the indispensable role of innovation in realizing SRA and, with examples, show that, as with CSR, there is a clear business case for SRA. We hope to inspire and help shape a future where automation and AI work for all.

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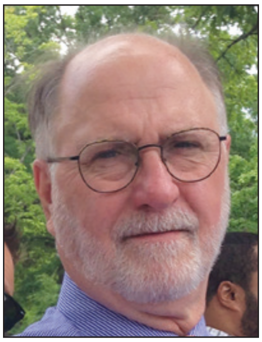
Paths to the engineering deanship seem fairly straightforward but work is needed to enhance their access to women and underrepresented minorities.

Paths to the Deanship in American Academic Engineering:
A Snapshot of Who, Where, and How



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Richard A. Skinner

This article presents findings from analysis of information on 186 full-time and interim/acting deans of engineering in the United States. The information consists of the deans' gender and race/ethnicity as well as their educational background and career trajectory—the universities from which they earned their doctorate,[1] previous administrative posts, and whether they assumed the deanship at their current institution or by relocating to another or from outside academia.

Background

The impetus for this study emerged from a June 2017 meeting of African American women engineering faculty celebrating the election of the first African American woman as president of the American Society for Engineering Education (ASEE). The celebration was tempered somewhat by the recognition that professional advancement for women in general and African American women in particular has been slow in academic engineering, notwithstanding the good faith efforts of individuals and organizations to improve that condition.

The African American women who came together were representatives of a very small group: 255 tenured full professors in a population of nearly

[1] All but one of the 186 deans have a doctorate. The other has an MBA.

27,000 tenured and tenure-track engineering faculty members (Yoder 2016). Their success may be instructive to efforts to increase diversity in engineering. Some are products of K–12 schools that remained characterized by racial segregation and unequal funding and resources well after *Brown v. Board of Education, Topeka*. More often than not, most of them were the only woman of color (or one of very few) in engineering programs, both as students and as professors. Their achievements in earning tenure and the rank of full professor, and the election of an African American woman as ASEE president, are all the more impressive in light of the barriers that had to be overcome.

Professional advancement for women in general and African American women in particular has been slow in academic engineering.

As intended, the meeting was given over to asking basic questions of both the honoree and the other women present: How did you succeed? What were the toughest barriers to your success? Who or what made that possible? To what do you aspire in academic engineering? If a deanship, why? Is there a single path that leads to a deanship, or might an ambitious engineer forge a different route?

The conversation was rich and ended with commitments to work together to advance African American women entering, remaining, and succeeding in academic engineering. One way to achieve those ends is to try to understand the path by which a person can aspire to and pursue advancement in academic engineering.[2] This analysis describes that path and the people who successfully navigated it.

[2] Interest in understanding was further piqued by the results of another study examining the leadership of research-intensive universities (Skinner 2018a). It showed a significant increase in the number of engineering deans who were named university presidents and provosts. Several African American women engineering faculty at the June 2017 gathering expressed their long-term interest in pursuing such posts.

Selection of Deans Studied

With this background, the choice of deans to consider in mapping a path to the deanship tilted toward engineering programs in which efforts were already under way to diversify both student populations and faculties. Sorting through and establishing the equivalence or effectiveness of each diversity-oriented activity or initiative at an engineering school or college proved impossible.

Fortunately, ASEE launched in 2014–15 the "Year of Action in Diversity," calling on engineering deans to commit themselves and their institutions to specific actions "to provide increased opportunity to pursue meaningful engineering careers to women and other underrepresented demographic groups" (ASEE 2018). The 186 signatories as of November 2017 are the subjects of this analysis, based on information about them available from their university's website.

Demographics

Gender, race/ethnicity, and place of origin remain powerful descriptors of persons who hold leadership positions in any of the professions in America, and academic engineering is no different. Each trait usually "stands for" a set of experiences and historical and cultural influences distinctive to the persons with those characteristics. The time may come when these aspects will cease to substitute for an understanding of an individual's unique experiences and attributes; that time has not come yet.

Gender and Race/Ethnicity

Overall, women remain underrepresented in leadership positions (Warner and Corley 2017). Yet more women than men enter and graduate from college. They earn nearly half of all law degrees, medical degrees, and MBAs, and account for 47 percent of the labor force and 59 percent of the college-educated, entry-level workforce. But leadership positions in virtually all professions remain disproportionately male, including the 70 percent of college and university presidents (ACE 2017).

Academic and professional engineering remains very much the province of white men and, as such, resembles much of the rest of higher education leadership. Women make up less than one fifth (18 percent) and underrepresented minorities account for 10 percent of the sample of deans analyzed here (table 1).

These figures stand out more clearly in comparison with analogous positions in academia and the population at large. Approximately one third of all deans in the arts and sciences are women (Behr and Schneider 2015), and among deans of teacher education women constitute just over half (AACTE 2018). But although women's representation among deans of engineering is almost exactly the same as their proportion of deans of medicine (17 percent; Skinner 2018b, table 1), the number and percentages of women joining academic medical faculties have increased substantially in a relatively short time—from 29 percent in 2001 (Jolliff et al. 2012) to 39 percent in 2015 (AAMC 2016, table 3)—whereas the representation of women on engineering faculty rose just 4 percent from 2006 to 2014, to only 16 percent of all professors (Yoder 2016).

Engineering also shares with its sibling professions a challenge in increasing the racial diversity of its student and faculty populations. African Americans constitute a scant 2.3 percent and Hispanics 3.7 percent of all engineering faculty, percentages that remain stubbornly unchanged since 2007 (Yoder 2016). Moreover, were it not for the engineering programs offered at historically black colleges and universities (HBCUs), Puerto Rican institutions, and Hispanic-serving universities, the representation from populations other than white persons would be smaller still.

Clearly, the representation of 14 African Americans (7 percent) among engineering deans is an accomplishment for those men and women, save for the fact that only two are women.

TABLE 1 Demographics of 186 US deans/interim deans of engineering

Gender	Percent	Number
Female	18%	33
Male	82%	153
Race/ethnicity		
African American	7%	14
Asian American	16%	29
Caribbean	0.5%	1
Latino/Hispanic/Chicano	2%	4
White	74%	137
Unable to determine	0.5%	1
Foreign-born/-educated		
Yes	29%	54
No	65%	121
Unable to determine	6%	11

Foreign Birth/Foreign Education

As resourceful as engineers are, they do not control their place of origin, so where they come from can be considered a demographic attribute rather than a choice.

The number of foreign-born or foreign-educated deans of engineering—54, or just under a third of the sample—reflects a variety of factors, including changes to immigration policy in 1965 that encouraged the relocation of Indians and South Koreans (Skinner 2013) and later Iranians and placed a premium on reunifying families. The latter enabled numerous students studying engineering in American programs to seek US citizenship, complete their studies, and join engineering faculties, then assist siblings to join them in America.

Other factors encouraging foreigners to immigrate to the United States were the rapid growth of demand for engineers in the US space program, increased world appetites for oil and other extractive resources, more intense global competition for manufactured goods, an increase in large-scale construction and civil projects, the emergence of information technologies, and political upheavals in countries such as Iran with educated populations. In most cases, women were not part of the labor demand in these areas and thus did not benefit from them. Only 8 of the 54 foreign-born/-educated deans are women.

To reiterate, then: American academic engineering leadership remains a male domain, only slightly less white than was the case in the past, and having benefitted from the immigration of talented, mostly male engineers.

Education and Professional Experience

The institution from which a dean earned a doctorate is not a unilateral decision on the part of the individual, but does reflect aspiration, application, and some element of luck. The engineering deans and interim deans in this sample have doctoral degrees from 83 universities, with some concentration in degrees from 21 institutions, which account for 46 (about one quarter) of the deans (table 2). Those 21 universities have familiar names, but they are not the only pathways by which to become a dean.

Previous employment experience outside higher education is also considered. This is somewhat problematic to determine since academic engineering entails

TABLE 2 Where US engineering deans and interim deans earn their doctorates

Number of deans/interim deans	University
13	MIT
8 each	Berkeley, Stanford
7	Michigan
6	Caltech
5 each	Georgia Tech, NC State, Penn State, Rice, Virginia Tech
4 each	Carnegie Mellon, Minnesota, Ohio State
3 each	Cambridge, Cincinnati, Cornell, CU Boulder, Notre Dame, Purdue, Texas Tech, UT Austin
2 each	17 universities
1 each	45 universities
3	Unable to determine
1	MBA rather than doctorate

frequent and often in-depth engagement with sectors beyond the campus. For this analysis, nonacademic professional experience is defined as full-time employment by entities other than colleges, universities, engineering associations, and/or professional societies. (A rotating assignment at the National Science Foundation [NSF] is considered outside employment.)

As with any professional program, engineering deans engage with nonacademic organizations and persons, including practicing engineers. And as is also the case in other professional fields, the importance of having worked full-time outside academia varies. Nevertheless, an effort was made to determine whether the 186 deans had been employed (other than as consultants) in industry, government, or not-for-profit organizations. Among the 186 deans in this sample, more than half—107 (57 percent)—have experience outside academia.

Given recent discussions in the academic engineering community about the relevance and "real world" applicability of curricula, pedagogy, and learning formats as well as the workplace readiness of engineering graduates, a stint as a practicing engineer outside academia may add to advancement prospects as an academic engineer.

Career Progression to the Deanship

The data suggest that the pathway to an engineering deanship generally adheres to a conventional route involving both support from one's immediate colleagues and experience with resource management, curriculum, students, academic personnel, and, increasingly, fundraising.

Tenure and the rank of full professor are almost universally considered minimal requirements for a deanship. Beyond that, service as a department chair or head is far and away the post from which one moves on to an engineering deanship (table 3), either immediately prior (39 percent) or one step before being appointed to the position (20 percent). In addition to handling duties and responsibilities comparable to those of a dean, a department chair typically has to have collegial ties and respect in a peer-driven environment. Summing across the first row of table 3 reveals that 110 (59 percent) of the 186 deans and interim deans chaired a department at some point before becoming dean.

Next in frequency of positions is that of associate or assistant dean, followed closely by interim dean. Depending on the size and complexity of the university's engineering program, the scope of responsibility in associate/assistant deanships can involve everything from oversight of student internships, co-op arrangements, and international experiences to the equivalent of a chief operating officer of the college or school and thus experience in most, if not all, of the functions of a dean.

The post of interim/acting dean ranks third in frequency as the position immediately prior to becoming dean in fact, whether at one's current or another university.

Relocation and Rankings

Analysis of the data from this sample reveals that "outsiders" make up nearly two thirds (63 percent) of current deans, suggesting that those who aspire to the position

TABLE 3 Progression to engineering deanship/interim deanship (sample of 186 deans)

Rank by frequency	Position immediately prior to deanship	Position 2 steps prior to deanship
1st	Department chair or head 72 (39%)	Department chair or head 38 (20%)
2nd	Associate or assistant dean 24 (13%)	Director[a] 20 (11%)
3rd	Interim dean 23 (12%)	Associate or assistant dean 19 (10%)
4th	Dean 19 (10%)	Interim chair 5 (3%)
5th	Director[a] 18 (10%)	Associate provost, vice president 4 (2%)
	Engineering/nonengineering faculty[b] 30 (16%)	Not applicable 100 (54%)

[a] The title "director" here involves administration of a project or laboratory of considerable scale and does not designate the head of an academic unit.
[b] Some of the engineering programs are housed with academic disciplines other than physics or materials science, one or both of which are sometimes housed with engineering.

TABLE 4 Relocation by engineering deans among institutions by ranking (based on *US News & World Report*)

New institution is…	Number (Percent)
a peer	48 (41%)
lower ranking	52 (44%)
higher ranking	14 (12%)
…or former institution is not a university[a]	4 (3%)

[a] These include colleges and nonacademic entities such as government agencies and businesses.

may well be required to forsake professional and personal ties to a university in order to gain an engineering deanship.

Separation may be eased somewhat by the standing of an incoming dean's new institution—if it is a peer or of a higher rank than the one left. Rankings that use both quantitative indicators and provosts' or presidents' perceptions of universities or programs other than their own are abundant.[3] To determine whether a dean moved to a university of greater, less, or the same prestige as that of the current institution, relocations were reviewed and categorized using both the institutional and the engineering program rankings of *US News & World Report* (based on quartiles of both rankings) (table 4).

Moves to peer institutions or to universities with lower ranking than that of the deans' former institution are the prevailing patterns of such relocations. Much less frequently does an individual move to a deanship at a university that ranks higher than the current or former institution.

Additional Factors

Most engineering deans are cited for their excellence as a teacher. They publish in peer-reviewed journals of national and international prominence and compete successfully for external funding to support research as well as a retinue of postdoctorates, doctoral and master's students, and undergraduates.

Service—be it to one's department, the college of engineering, the university, academic and professional associations, licensing agencies, government and intergovernmental organizations—is expected, though its relative weight vis-à-vis research and publications,

[3] An incomplete list of college rankings includes those of *US News & World Report*, *Princeton Review*, *Wall Street Journal/Times Higher Education*, *The Economist*, *Forbes*, *Fiske Guide*, and *Kiplinger Business*.

grantsmanship, and teaching varies among institutions and even departments in the same college of engineering.

Unlike their brethren in academic medicine (and, as noted above, deans of engineering and medicine are predominantly male), the necessary formal education and training in engineering at the undergraduate and graduate levels can be shorter, so professional growth and advancement can begin earlier such that a precocious academic engineer may be named a dean relatively early in her career.

Concluding Thoughts

The path to becoming a dean of engineering is straightforward enough: aligned to the conventions of universities but respectful of time spent beyond the cloisters in the practice of engineering. Preparation for seeking a deanship almost always entails successful service as a department chair or an associate or assistant dean. Directing large-scale projects of special significance can sometimes substitute for experience as a chair or associate dean, but the project must demonstrate skills commensurate with those of the more conventional stages along the path to a deanship.

Attending the "right school"—especially the right doctoral-granting university—strengthens one's candidacy for a deanship in engineering, but the circle of elite institutions from which to begin one's career is neither especially small nor fixed in its membership. And being dean at one of the higher-ranked schools affords more opportunities, including the chance to be provost or president of a high-ranking university (Skinner 2018a).

This brief portrait of pathways to engineering deanships does not do justice to the challenges, expectations, and complexities of the position or, for that matter, to the extraordinary success and international acclaim for American engineering, both within the academy and beyond. It may, however, suggest areas for improvement to expand access and enhance representation so that the people in these important positions better reflect the vibrant diversity of their students and the population. For example, research is needed to identify where along the pipeline of students—beginning in K–12—the numbers of currently underrepresented populations in engineering can be increased significantly and sustainably. Research may also consider what role deans should play in encouraging faculty members to explore administrative posts that may position them on the path to higher appointments.

Acknowledgment

First-class editing typically goes unnoticed and is seldom acknowledged for the value it brings to prose. In this case, I commend Cameron Fletcher for going well beyond the requirements of her post to improve my writing and my reasoning. If not for the risk of her being tarnished by something I have written, I suggest she is a coauthor of this piece.

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An Interview with . . .

Maverick McNealy, Pro Golfer

Maverick McNealy

RON LATANISION (RML): Hi, Maverick. I understand you're taking a little break from the PGA tour?

MAVERICK McNEALY: Yes, I'm practicing, playing with friends, and I'll spend time with family in the off-season as well. It's nice to be home for a little while.

RML: When is your next tournament?

MR. McNEALY: I have a few small events in November and early December, then the first event of the Web.com Tour season is the first week of January.

RML: Well, we are happy to have an opportunity to get some of your thoughts on how engineering has affected your life and your prospects as a member of the tour. Your Stanford degree is in management science and engineering. Is there a major engineering discipline associated with that, or what kind of engineering exposure did you have?

MR. McNEALY: Management science and engineering (MSE) is a really broad major. It's 120 units, which is a lot more than most other majors and it felt like I took core classes from a bunch of different majors—econ, math, a lot of statistics and probability because I did the finance and decision analysis track and concentration. I would say more than half the classes I took for my major were along the lines of probabilistic analysis, statistical modeling, intro to data science, things like that. I had to take a few core engineering classes and hard sciences but primarily based around decision engineering.

CAMERON FLETCHER (CHF): What were the core engineering classes you took?

MR. McNEALY: It was kind of odds and ends to fulfill requirements. I took one on energy production and storage, which was a little more pertinent than I anticipated because halfway through my time at Stanford the university claimed half of our practice facility and built what was essentially a huge heat exchanger on it: every time a building was being air conditioned the excess heat from there was used to generate electricity, which is pretty cool. We spent two days in our class going over that. And obviously there was a physics requirement—I prefer physics to chemistry by a long shot—but it was again less hard science and more math.

CHF: Before you decided to go pro as a golfer, what were you thinking you might do with this background?

MR. McNEALY: I honestly didn't really know. I interned the summer before I started college and between my freshman and sophomore years at a startup called Wayin in Denver. I took a couple weeks between the tournaments I was playing and basically did whatever odds and ends they threw at me. I enjoyed taking a lot of information and trying to make something useful out of it.

When I was reading through the different majors, I knew I wanted to do something in the engineering school based on what I enjoyed in high school, and MSE seemed to be about how to make good decisions—that's what I enjoyed doing. I figured that out from my time interning, and that way of thinking has translated into the way I go about golf.

When I started school I didn't think I was ever going to be good enough to play professional golf. I didn't think that was even an option. I was just excited to be on the team and have a spot to play and that's why I guess people made a big deal about me not knowing whether I was going pro until late in my senior year.

But I went to school for school first and to be the best teammate I could be, and I ended up having some pretty cool opportunities in golf. The ability to make decisions with a lot of input did help me with the decision to turn pro because there's a lot of things to consider. And I think I made a pretty good decision.

RML: I have an engineering question for you. I taught at MIT in the Materials Science and Engineering Department for nearly 30 years and I remember some of my colleagues being interested in sports equipment—skis, golf clubs, for example. They were looking at new materials, like carbon fiber or even depleted uranium of all things, for the heads on golf clubs and drivers. Do you have any experience or thoughts on that?

MR. McNEALY: Here's kind of a longer way to answer that question. There were three equipment companies I was considering when I was turning pro and thinking about who to sign with: Callaway, TaylorMade, and Titleist—the three biggest golf equipment companies.

The ability to make decisions with a lot of input helped me with the decision to turn pro.

I visited the Callaway headquarters in Carlsbad (CA) and they were smart, they knew exactly how to get my attention: they walked me through their entire R&D department. I got to see the way they designed their Epic driver, which completely changed the golf club market in the US and made Callaway the number one driver company.

There's something in golf called characteristic time (CT), it's a way to measure how fast a driver is, how fast a ball can come off the driver face. There's a legal limit and some pros handpick heads that are close to it but they have to work around the limit to find ways to make the driver head faster.

One of the things Callaway did with its Jailbreak Technology is they put two bars behind the driver face, connecting the bottom of the driver to the crown, but they found that they were losing energy as the crown bubbled up at impact. So they anchored it at two points to minimize the amount of energy loss from the crown deforming.

RML: To stiffen it somewhat, is that the idea?

MR. McNEALY: Pretty much. PXG is trying to copy that by creating a more rigid titanium top to their driver to minimize that effect as well, but at this point it's really about who can develop lighter and stronger materials to move weight around in the driver head to create the fastest and most stable head.

RML: Does the PGA oversee this in any way? Are there regulatory considerations from the PGA about what can and cannot be done in terms of producing clubs?

MR. McNEALY: Actually the USGA is the governing body that creates the rules and regulations on golf clubs. If you win a major your clubs are often tested to make sure they are within legal limits. For example, there are limits to the dimensions of grooves on a wedge to prevent excess spin. And there's obviously length limits and things like that.

But some club companies work around PGA's limits. Interestingly enough, a driver that you buy off the rack in a store is sometimes above the legal CT limit.

I know that Callaway, since Chip Brewer took over four years ago, is extremely strict on quality control. I also know of cases where guys have gotten in trouble from playing an off-the-rack driver that was not legal.

RML: I know the same kinds of considerations are given with, for example, skis. If you're a professional or Olympic-style skier, the chances are you want the very best, fastest, most flexible skis. Some people have actually built skis that have transducers in them so they can respond to any flexure and make corrections. I don't know if they are allowed in competition but I know they are available for the public.

Do you get involved with Callaway in the process of developing or designing golf equipment of any kind?

MR. McNEALY: Callaway uses their players a lot for feedback—we're kind of the testers. A lot of players have really good, tight skills as to how a club performs—sound, feel, ball flight…. For example, I can guess the spin rate within 1,000 RPM, usually 500, of pretty much any club.

I think I take an interest, more than most players, in what's creating what I'm feeling and seeing. A simple example is changing the center of gravity of a driver head. If the center of gravity is low, the ball will launch high with less spin because there's gear effect on the face. If you hit the driver in the center, the bottom will be more stable than the top; the top will deflect open and that puts a higher launch and more spin on the ball. So if I have a driver that's going left, I'll put either red tape or internal glue on the toe to create more left to right spin or less right to left spin.

CHF: Are you allowed to modify your clubs when you're playing professionally?

MR. McNEALY: Yes. We can't do that mid-round but we can do it between rounds. I would say just about every professional has a handpicked head that is within a couple degrees or a couple tenths of a degree of the loft and lie angle that they like to see. From there we can modify the center of gravity. So almost all my drivers have red tape on the toe because I hate to see a ball going left.

Another thing I've gotten really interested in is the dynamics of the golf ball—performance in the wind, ball flight and spin rates. It's really important to pay attention to.

One of the things Callaway has done with the last two iterations of their golf ball is they've created a less dense, bigger core, which has allowed them to create a heavier mantle, which increases the moment of inertia (MOI). The challenge is how to create a big, less dense, lighter core that won't be brittle and crack over a certain number of times that you're hitting it with 118 mph driver speed.

They've been able to move weight toward the perimeter in these balls to increase ball speed. I was just testing two days ago with them on their new driver and ball and the ball was 3 miles an hour faster than the ball I've been playing.

CHF: How do you gauge the speed of these balls when you're out on the course by yourself?

MR. McNEALY: There's a product called TrackMan; it's probably the most common one, but there's a couple versions. It's essentially a modified Doppler radar. Behind players on the driving range, there's a little orange box about an inch and a half thick that measures all the watched conditions of the golf ball—launch angle, speed, spin rate, spin direction, spin axis—as well as all the characteristics in the club at impact—speed, angle of attack, path, space angle, face deflection to a certain degree. It infers face deflection and from there we can tell how the club and ball are performing.

For me it's a huge club fitting tool and club testing tool. That's how I can now guess within a few hundred RPM where the ball is spinning, which direction it's launching, and use that for club fitting.

RML: If you need to make corrections to your swing is that an avenue that allows you to pursue that?

MR. McNEALY: It is. I think sometimes guys get too lost in the numbers, they're too focused on getting perfect numbers. There's a balance between play and feel and the numbers. For me, it's always a good second opinion but honestly I use it more for club fitting and then adjusting to conditions.

I've gotten interested in the dynamics of the golf ball—performance in the wind, ball flight and spin rates.

Another thing that's really important is the condition of where you're playing. Las Vegas is at 3,000 feet. As a general rule, the ball goes about 1 to 2 percent farther per 1,000 feet of elevation. This is obviously extremely important when golfers nitpick about 1 or 2 yards when they're hitting a 230-yard shot.

Launch angle also impacts that. If I hit a high shot with a lot of spin, it's going to go farther than a low shot with less spin at altitude. And humidity affects the ball, especially when it's warm. If it's cold and humid, the air plays heavier and the ball goes shorter. If it's hot and humid, the ball actually stays in the air longer for whatever reason.

Temperature has an enormous impact—for the golf ball more than the actual air. If the golf ball is warmed up 10 degrees, it can go 5–6 yards farther.

CHF: Are there restrictions governing the temperature of the golf ball when you play?

MR. McNEALY: So you're not allowed to intentionally warm up a golf ball. You can have a handwarmer on a cold day, they can't really get you in trouble for that, but I keep my handwarmers in my gloves and I don't put them in the same pocket with the ball—partly because I'd be worried that half the ball would get warmer than the other half and what that would do.

A warmed golf ball can go 5–6 yards farther, so you're not allowed to intentionally warm up the ball.

So yes there are rules. The USGA thinks of stuff like that. I actually once saw a guy rubbing his handwarmer on his driver. That's 100 percent against the rules.

RML: I can tell that your interest in science and engineering pervades your game. You're interested not only in playing and the camaraderie of the folks on the tour but also in the technology that is part of the game.

MR. McNEALY: My freshman year there were a couple guys on the team, Cameron Wilson and Patrick Rogers. Cameron won the national championship my freshman year and Patrick is on the PGA tour. They taught me a lot about TrackMan and ball flight and how to generate the most spin on a pit shot and what the optimal impact conditions are. Also how important it is to clean your wedge between every shot because if you have grass on your club face it's going to almost cut the spin in half as opposed to if you're using a dry ball and a dry wedge. Things like that were really interesting to me.

RML: Do they have some experience with science or engineering in their backgrounds or have they picked up a lot from playing?

MR. McNEALY: Patrick was a sociology major and Cameron was a history major, but they both really understood how to use TrackMan technology and how to design a golf club to impact what they're seeing and feeling. So they weren't necessarily engineers by training but they used a lot of that information.

CHF: Maverick, you're clearly in to all the minutiae of the technical side of the game. I'm wondering how much you get to talk about all of this with other golfers when you're out and about.

MR. McNEALY: It really depends. There's a huge range and there's a lot of ways to play good golf. With a lot of guys all they care about is whether the club does what they want it do, and there's a lot to be said for that. There are other guys who are way more interested in things like this. We're the minority, but I would say most professionals understand at least the most important bits of why they're seeing what they're seeing and things like that.

I really enjoy being partnered with Callaway because they can talk my ear off about this stuff and there's a lot that I don't understand, which is really exciting for me. I love talking to their R&D guys and the guys who are actually making and building the clubs. And I love how they take player feedback and translate it into something physical with the makeup of clubs.

For example, if the club doesn't feel right in my hand, if it doesn't swing right or it doesn't create the ball flight that I want to see or that I picture on a given shot, that drives me nuts. So Callaway built me a set of irons that were the exact weight, swing weight (which is kind of a way to measure static torque), length, head weight—everything was identical, even the frequency of the way it swings. But I said, "It doesn't feel like a club to me. It feels like there's a big glob of metal on the end of a stick. That's the best way I can describe it."

I said, "Can we take apart my set of irons and the set you built?" We did and they found that they had put a 6 gram plug in the heel to get the swing weight correct as opposed to the 4 gram plug that was in my iron. We took the 6 grams out, put the 4 grams in and put two rows of red tape on the back of the iron so that it maps the profile of the iron itself, and it felt back to normal.

That's what I love about these guys. As nitpicky as something I might say sounds, they find a way to fix it or the reason why I'm feeling what I'm feeling with the club. Every single time I've come to them with something, they fix it.

RML: That's a real testimonial to your sort of instinct or sense of feeling with clubs. It's almost like it's an extension of your body. If you can come to the point where you recognize those sorts of subtle differences, that's pretty impressive.

MR. McNEALY: Well, if you're swinging a 3½-foot-long club where the club head is moving at 110 miles an hour, those 2 grams feel like a lot more!

RML: That reminds me—I'm not a particularly good golfer, I play occasionally; my brother's a much more active golfer. But a few years ago I had some lessons from a pro at Hilton Head and when he came out on the course he was limping. I thought, 'That's not a good sign.' He was going to play some tournament in the not too distant future. I said, "What's the problem? You don't look like you're in very good shape." He said something like, Swinging a golf club is not a natural act. I thought that was pretty informative! It reminds me of this marvelous comeback that Tiger Woods is making, because I think he's had some major back problems. What are your thoughts on this? I understand Tiger is also a Stanford alum, is that correct?

MR. McNEALY: He is, yes. Just over a year ago now, we were having a team meeting while I was with the Stanford guys and Tiger was playing his first tournament back, in the Bahamas. We were all saying, "Is Tiger going to win again?" I thought, 'If Tiger can go a year without a setback from injury he will win again, because he's that good.' And I think his swing is awesome now.

Tiger is the best approach player—hitting from the fairway to the green—of any player on tour in the last 10 years, every single year that he's had enough rounds to be eligible to be ranked, which is incredible.

The way they measure that is with a thing called ShotLink: sensors and lasers on each hole track where every player hits every single shot. So on the PGA Tour it's possible to go back and see where every single one of Tiger's shots was played from.

From this information a statistician at Columbia named Mark Broadie created the "strokes gained" metric, which shows how much better you did than the average of a PGA Tour player. He found that from, say, 7 feet, a PGA Tour player averages 1.5 strokes to hole, which means half the time they make it, half the time they two putt. So if you make a 7-footer you gain half a shot, and if you miss a 7-footer you lose half a shot.

Broadie did this for all distances in all lies—fairway, T box, rough, bunker, trees, and greens. In other words, if there are 175 yards and the strokes to hole is 2.8 and you hit the ball to 7 feet and the next strokes to hole is 1.5, you gained 0.3 shots. That's quick math.

All these numbers show that Tiger is number one in strokes gained approach average on the tour in every year in the last 10 that he's been ranked.

RML: I like Tiger Woods a lot. I watched him develop over the years. A few years ago I saw him on a tour and he hit a shot and then buckled, literally onto his knees because his hip, back, spine, something was obviously bothering him. And to see him play in the last couple tournaments and then especially the one he just won, it's absolutely stunning. What a comeback. It's great to watch.

What about the comment about swinging not being a natural act—do you do anything in terms of training or exercising to keep your back in good shape? What are your thoughts on that, from the physiology standpoint?

MR. McNEALY: I had no back or hip problems until my junior year of college—and I played ice hockey until my senior year of high school. You think in hockey you get hit a lot, but I didn't have any injuries from hockey.

On the contrary, I had extremely strong and mobile legs and hips. Generally where golfers run into back trouble (this is an overgeneralization) they have weak or immobile hips. The way my physical therapist explained it, your body alternates mobile and immobile joints: your ankle is a mobile joint, your knee is immobile, your hips are mobile, your lower back is immobile, your upper back thoracic is mobile, the base of your neck is immobile, and then the upper neck is mobile. Same with wrists, elbows, shoulder, rotator cuff, things like that.

If a golfer's hip complex becomes immobile then the lower back has to take on some of that movement because a swing is a very fast and violent and asymmetrical motion for the body. That's where a lot of golfers run into problems.

Tiger Woods is the best approach player—hitting from the fairway to the green—of any player on tour in the last 10 years.

About 2 years after I stopped playing hockey I had an injury. And at the end of my senior year of college I sprained and dislocated my left SI joint in my hip. I struggled with that for upwards of 6 months. Then I just started skating again, because everything my physical therapist was telling me to do felt like it was strengthening hockey muscles. So I thought, 'Why don't I just go skate some more?' Within my first 15 minutes on the ice I felt my lower back opening up and releasing and relaxing as my hips complex woke up. It was one of the weirdest things I've ever felt. But it felt amazing.

Maverick McNealy shares a fistbump with his father.

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I also have a left-handed club in my bag. I can barely hit a left-handed shot 100 yards and I chunk it half the time. But since I swing right-handed 500 times a day, when I swing left-handed 15 to 20 times I find that my right hip capsule is really tight, part of my right forearm and left hand are weak and tight, and so is part of my right shoulder that basically isn't used. So I've been trying to balance out my body that way because the golf swing is a very asymmetrical motion.

RML: I can see that you're a student of not only the mechanics and physical dimensions but also the physiology of the game. And that's a good thing. I think of other professional athletes, like Tom Brady, who at 41 years old is probably one of the most fit people on the planet. As far as I can tell it's because he really works at it and understands it.

MR. McNEALY: I read his book on the way he trains: he trains to maximize pliability—not necessarily flexibility or strength—which he defines as the elasticity of muscle potential. So he doesn't stretch. He does this breaking active release therapy of expanding and contracting and relaxing muscles while pressure is being applied, to lengthen and soften muscles.

That was the start of my recovery from these injuries. I stopped lifting heavy weights. I started not stretching as much, which I thought actually put some strain on some of my joints. I spent a lot of time with the vibrating foam roller, which is way more effective than a normal foam roller—it kind of tricks your muscles and nerves into relaxing because the pulsating mimics the signals that your brain sends to your muscles to expand or contract. And it hurts less, which is great.

In addition, I started playing more hockey and strengthening the right muscles in the hip block complex. In the last two weeks or so I've been able to go back to doing some of the ice hockey workouts and lifts I did, and instead of feeling pain and discomfort in my hip I feel stronger and like it's more protected from golf-related stress and overuse injury.

RML: I have a sort of historical question. I know your dad, Scott McNealy, by name from Sun Microsystems. I don't know much about your grandfather, Raymond McNealy, but I've read that he worked in Detroit in the automotive industry. Is he an engineer or what's his background? I'm just curious.

MR. McNEALY: He was vice chair of American Motors. I don't think he was an engineer but he worked there for a while. That's why we have the Detroit connection and my brothers and I are all named after American cars—besides me there's Dakota, Colt, and Scout.

RML: So you're a Ford Maverick and –

MR. McNEALY: There's the Dodge Dakota, Dodge Colt, and Jeep Scout.

RML: Your grandfather must be delighted. What an interesting story.

Well, Maverick, I think we've taken as much time as we promised we'd take this morning. You're a very young man but I can see that you're going to play an important role in golf's future in a number of ways. I'm so delighted we had this opportunity to talk with you. We appreciate the time you've taken and we'll keep an eye on the PGA tours.

CHF: Thank you, Maverick. This was certainly very informative and interesting.

MR. McNEALY: Yes, there's a lot of stuff that goes on in golf. We love speed and love to hit it farther so we try and figure out as many ways we can do that. Thanks, you guys.

NAE News and Notes

NAE Newsmakers

Pedro J.J. Alvarez, George R. Brown Professor of Civil and Environmental Engineering and director, Center for Nanotechnology-Enabled Water Treatment, Rice University, has received the **2018 Perry L. McCarty Founders' Award** from the Association of Environmental Engineering and Science Professors. The award recognizes "significant contributions in environmental engineering, education, research and practice." Dr. Alvarez received the award October 1 at the annual Water Environment Federation's Technical Exhibition and Conference in New Orleans.

Diran Apelian, Alcoa-Howmet Professor of Mechanical Engineering and Founding Director, Metal Processing Institute, Worcester Polytechnic Institute, received WPI's **2018 Innovator of the Year Award**. The award, established in 2011 to recognize graduates and friends of the university who have demonstrated exemplary accomplishments as innovators, was presented November 1. The ceremony included an address by Dr. Apelian, an internationally recognized authority on metallurgy and recycling. He is the first WPI faculty member to receive the honor.

Arthur Ashkin, retired member of the technical staff, Bell Labs, and **Gérard A. Mourou**, director, École Polytechnique, have won the **Nobel Prize in Physics**. The prize is shared with Donna Strickland of the University of Waterloo, Canada, only the third woman in history to receive it. The recipients were cited "for groundbreaking inventions in the field of laser physics" with half to Dr. Ashkin "for the optical tweezers and their application to biological systems," and the other half jointly to Drs. Mourou and Strickland "for their method of generating high-intensity, ultra-short optical pulses." On October 3, the **2018 Nobel Prize for Chemistry** was awarded to **Frances H. Arnold**, George P. Smith, and Gregory P. Winter for their work that harnessed evolutionary principles to create proteins. Dr. Arnold, Linus Pauling Professor of Chemical Engineering, Bioengineering and Biochemistry, California Institute of Technology, won half of the prize "for the directed evolution of enzymes."

Corale L. Brierley, principal, Brierley Consultancy LLC, and NAE vice president, received the second-ever New Mexico Tech **President's Medal**. The medal is conferred on individuals who significantly support the university through donations or gifts, appreciably advance STEM in higher education, enhance the professional growth of the sciences and engineering in the service of humankind, and/or significantly enhance the reputation of New Mexico Tech nationally or globally. Dr. Brierley was lauded for her contributions to the mining industry and the National Academy of Engineering.

Jacqueline H. Chen, Distinguished Member of Technical Staff, Sandia National Laboratories, has been elected a **fellow of the American Physical Society**. She was honored for fundamental insights into turbulence-chemistry interactions revealed through massively parallel direct numerical simulations.

Thomas M. Cook, founding partner, Decision Analytics International, is one of five new members appointed to CSAC, the US Census Bureau's Census Scientific Advisory Committee, which provides advice on the design, operation, and implementation of Bureau programs.

Maryellen L. Giger, A.N. Pritzker Professor of Radiology and Medical Physics and vice chair for basic science research, Department of Radiology, University of Chicago, received the **2018 iCON Innovator Award** on October 2 at the 12th annual iBIO iCON Awards Dinner in Chicago. The award celebrates the accomplishments of outstanding innovators and leaders whose work provides the basis for life sciences developments worldwide. Dr. Giger is considered a pioneer in the development of computer-aided diagnosis. In 2015 she received the **William D. Coolidge Gold Medal** from the American Association of Physicists in Medicine, which recognizes an AAPM member for an eminent career in medical physics and is the highest award given by the AAPM. In 2013 she was named by the International Congress on Medical Physics (ICMP) as **one of the 50 medical physicists with the most impact on the field in the last 50 years**. [These awards were not previously reported in *The Bridge*.]

Irvin Glassman, Robert H. Goddard Professor of Mechanical and Aerospace Engineering Emeritus, Princeton University, was awarded the 2018 AIAA/ASME/SAE International/VFS **Daniel Guggenheim Medal** on August 18. He received the medal "in recognition of his profound impact on the application of combustion science and engineering to propulsion research and the successful development of propulsion systems."

Joseph W. Goodman, William E. Ayer Professor Emeritus, Stanford University, has been named **2018 Honorary Member of the Optical Society**. Honorary membership is the most distinguished of all OSA member categories, bestowed on individuals who have made seminal contributions to the field of optics as determined by unanimous vote of the OSA board of directors. Dr. Goodman is honored for fundamental contributions in the fields of Fourier optics and optical information processing through his research, teaching, and classic textbooks.

Jeffrey A. Hubbell, Barry L. MacLean Professor of Molecular Engineering Innovation and Enterprise, University of Chicago, has been **elected to the National Academy of Medicine** for "pioneering the development of cell responsive (bioactive) materials and inventing biomaterials that are now widely utilized in regenerative medicine." Dr. Hubbell also received the **2018 James Bailey Award** from the Society for Biological Engineering. The award was presented during AIChE's annual meeting, where Dr. Hubbell presented the Bailey Award Lecture, "Turning Immunity On and Off," on October 30.

Shirley Ann Jackson, president, Rensselaer Polytechnic Institute, received the **W.E.B. Du Bois Medal** presented by the Hutchins Center for African & African American Research at Harvard University. Du Bois medalists are chosen for their significant contributions to African and African American history and culture, and, more broadly, are individuals who advocate for intercultural understanding and human rights in an increasingly global and interconnected world. Dr. Jackson received the medal October 11 in a ceremony during the sixth annual Hutchins Center Honors.

Chad A. Mirkin, director, International Institute for Nanotechnology and George B. Rathmann Professor of Chemistry, Northwestern University, received the **Friendship Award**, China's highest recognition bestowed on "foreign experts who have made outstanding contributions to the nation" in a ceremony held in Beijing on September 29 as part of National Chinese Day festivities. The Friendship Award is effectively the country's National Medal of Honor for foreign experts.

Jonathan M. Rothberg, chair, 4Catalyzer, has been awarded the **Award for Excellence in Molecular Diagnostics** by the Association for Molecular Pathology for his groundbreaking work and noteworthy achievements in genomics. He is the founder of multiple life science and medical device companies. The award was presented during the AMP 2018 annual meeting and expo held November 1–3 in San Antonio. After the award presentation Dr. Rothberg delivered a keynote lecture, "Reimagining Health Care: Next Generation DNA Sequencing to Ultrasound-on-a-Chip."

Bridget R. Scanlon, senior research scientist, Bureau of Economic Geology, University of Texas at Austin, received the **Hydrologic Sciences Award** from the American Geophysical Union during its fall meeting December 10−14 in Washington. The award is presented for outstanding contributions to the science of hydrology over a career and is the highest disciplinary recognition for senior scientists in the hydrology section of AGU.

Xiang Zhang, president and vice chancellor, University of Hong Kong, was awarded the **2017 A.C. Eringen Medal** from the Society of Engineering Science in recognition of his contributions in micro-nano scale engineering for microelectronics and photonics. He received the award at the society's 55th annual technical meeting October 10–12 in Madrid.

The IEEE Computer Society chose two NAE members to receive prestigious awards. **Linda R. Petzold**, professor, Department of Computer Science, University of California, Santa Barbara, was selected to receive the **2018 Sidney Fernbach Award**, which recognizes outstanding contributions in the application of high-performance computers using innovative approaches. Dr. Petzold was cited for "pioneering contributions to numerical methods and software for differential-algebraic systems and for discrete stochastic simulation." **David E. Shaw**, chief scientist, D.E. Shaw Research, received the **2018 Seymour Cray Computer Engineering Award**, which is presented in recognition of innovative contributions to high-performance computing systems that best exemplify the creative spirit demonstrated by Seymour Cray. Dr. Shaw was recognized "for the design of special-purpose supercomputers for biomolecular simulations."

The 2018 American Chemical Society presented awards to **C. Grant Willson**, Rashid Engineering Regents Chair, Department of Chemical Engineering, University of Texas, Austin, and **Elsa Reichmanis**, Department of Chemical and Biomolecular Engineering, Georgia Institute of Technology. Dr. Willson received the **ACS Award in Polymer Chemistry** for "fundamental advances in synthetic polymer chemistry," and Dr. Reichmanis was presented the **ACS Award in the Chemistry of Materials** for "pioneering research in design and development of polymer/organic materials and processes for advanced electronics and photonics and service to chemistry society."

ACS has announced its 2019 award recipients, who will be honored at the Society's national meeting in Orlando in April. **Naomi J. Halas**, Stanley C. Moore Professor, Department of Electrical and Computer Engineering, Rice University, will receive the **Award in Colloid Chemistry**. **Jerald L. Schnoor**, Allen S. Henry Chair Professor and codirector, Center for Global & Regional Environmental Research, University of Iowa, will receive the **Award for Creative Advances in Environmental Science and Technology**. **Krzysztof Matyjaszewski**, J.C. Warner University Professor of Natural Science, Carnegie Mellon University, will be presented the **ACS Award in the Chemistry of Materials**.

The Hagler Institute for Advanced Study at Texas A&M University has announced its **2018–2019 Faculty Fellows** who will be inducted at the annual gala in early 2019. Faculty Fellows are selected from top scholars who have distinguished themselves through outstanding professional accomplishments or significant recognition. Among those chosen are **Yonggang Huang**, Walter P. Murphy Professor of Engineering, Northwestern University; **H. Vincent Poor**, Michael Henry Strater University Professor, Princeton University; and **Andrea Rinaldo**, professor of hydrology and hydraulic engineering, École Polytechnique Fédérale de Lausanne.

The **Albert Nelson Marquis Lifetime Achievement Award** is bestowed on individuals who have many years' experience in their professional network and have been noted for achievements, leadership qualities, and credentials and successes accrued in their field. Recent recipients of this award are **Norman R. Augustine**, retired chair and CEO, Lockheed Martin Corporation; **Larry A. Coldren**, Fred Kavli Professor of Optoelectronics and Sensors, University of California, Santa Barbara; **John P. Hirth**, professor emeritus, School of Mechanical and Materials Engineering, Washington State University; **Jagdish Narayan**, John C.C. Fan Foundation Distinguished Chair, Materials Science and Engineering, North Carolina State University; **Lanny A. Robbins**, retired Distinguished Faculty Fellow, Chemical and Biological Engineering, Iowa State University; **William A. Sirignano**, Henry Samueli Endowed Chair in Engineering, University of California, Irvine; **Robert L. Street**, William and Martha Campbell Professor Emeritus, Stanford University; and **T. Leslie Youd**, professor emeritus, Department of Civil Engineering, Brigham Young University.

2018 Annual Meeting

The 2018 NAE annual meeting was held September 30–October 1 at the National Academy of Sciences building in Washington, DC. This year's meeting had a record high attendance of more than 850 members, family, and guests.

NAE chair **Gordon England** opened the public session on Sunday, reminding members of the importance of the NAE's responsibility to serve the nation and of the need for adequate funding to ensure that the Academy can effectively achieve this mission.

President **C. D. Mote, Jr.** then delivered his annual address, "Times of Accelerating Change Call for the NAE to Change with Them." Among his observations about the impacts of change for society and the NAE, he reported that the three Academies are developing codes of conduct for members to address the problem of sexual harassment in the STEM fields. He also announced the launch of a major fundraising campaign, *Leadership in a World of Accelerating Change*, with a goal for the NAE of $100 million by December 31, 2022. The funds will strengthen the NAE's capacity to fulfill its mission of advising the government and enable it to respond to opportunities and unexpected crises, as well as provide critical support for change-

Class of 2018.

enabling NAE programs such as the Grand Challenges Scholars Program, *EngineerGirl*, the US and bilateral Frontiers of Engineering symposia, and the Center for Engineering Ethics and Society.

This was followed by induction of the class of 2018 and 3 members from the class of 2017 who were unable to attend last year. Introductions were made by NAE executive officer **Alton D. Romig, Jr**.

The program continued with the presentation of the 2018 Ramo Founders and Bueche Awards. The 2018 **Simon Ramo Founders Award** was presented to **Thomas Kailath**, Hitachi America Professor of Engineering Emeritus, Department of Electrical Engineering, Stanford University, "for pioneering contributions to diverse fields of electrical engineering and for leadership in technology commercialization and in engineering education, guiding a stellar array of young scholars." **Venkatesh Narayanamurti**, Benjamin Peirce Research Professor of Technology and Public Policy, Paulson School of Engineering and Applied Sciences and Kennedy School of Government, Harvard University, received the **Arthur M. Bueche Award** "for seminal contributions to condensed matter physics and visionary leadership of multidisciplinary research in industry, academia, and national labs that generated research and engineering advances."

The **Bernard M. Gordon Prize for Innovation in Engineering and Technology Education Lecture** featured **Paul G. Yock**, Martha Meier Weiland Professor of Medicine and founder and director of the Stanford Byers Center for Biodesign, which uses a needs-driven approach to train the next generation of multidisciplinary leaders who will create innovations in health technology. It is a mentor-guided, entrepreneurial, and immersive experience that instills an understanding of the innovation process in several fields. Through the Biodesign program, Dr. Yock has shown that innovation is a discipline that can be both organized and learned, allowing students to build sustainable careers as innovators and leaders. Since its establishment in 2001, a number of programs around the world have based their curriculum on its model.

After a break, Dr. Mote introduced two plenary speakers who shared their expertise on emerging challenges of ever-expanding applications of computing and information technology. **Diane B. Greene**, chief executive officer of Google Cloud, discussed "extended intelligence" based on the interaction of humans and machines. Mike Walker, principal researcher with

25-Year anniversary members, l to r: Peter M. Banks, Sidney Leibovich, Deborah J. Nightingale.

30-Year anniversary members, l to r: C. D. Mote, Jr., Ward O. Winer, Richard C. Alkire.

At the forum: Batya Friedman, Mike Walker, Aanchal Gupta, Lea Kissner, Ali Velshi.

Microsoft Research NExT, described efforts to "Secure the Internet of Things with Automation."[1]

Monday began with the annual business session for members, followed by the forum on "Privacy and Security in the 21st Century – Who Knows and Who Controls?" The forum panelists were Batya Friedman, professor in the University of Washington Information School; Aanchal Gupta, director of security at Facebook; Lea Kissner, global lead of privacy technologies at Google; and Mike Walker, who described opportunities and challenges in securing online applications. Ali Velshi of *NBC News* and *MSNBC Live* moderated the panel discussion and handled the many unsettling questions from the audience about IT security in our daily lives.[2]

On Monday afternoon members and foreign members participated in NAE section meetings at the NAS Building and Keck Center. The meeting concluded with a reception and dinner dance at the Mayflower Hotel.

The next annual meeting is scheduled for October 6–7, 2019, in Washington, DC. *Mark your calendars!*

[1] Their presentations are available online at https://www.youtube.com/watch?v=5mpvz2Pkmb0&feature=youtu.be.

[2] Videos of the forum are available at https://www.youtube.com/watch?v=XGej4LNvc7I&feature=youtu.be.

Remarks by NAE Chair Gordon R. England

Gordon R. England

Good afternoon and welcome to the 2018 National Academy of Engineering annual meeting. It is always a pleasure to see so many of our "old timers" back again. Enjoy your time with friends and colleagues. A very special welcome to our newly elected members and their families.

This is my third annual meeting as chair of the NAE Council and each year I have gained a deeper appreciation for the exemplary leadership of President Dan Mote, the knowledge and commitment of the Council, and the hard work of the staff. It is a distinct pleasure to work with each of them and I am deeply appreciative of their friendship, support, and dedication.

For our new members, and as a reminder for our old hands, the NAE is not an honor society. While it is an honor to be a member of the Academy, our purpose is service to the profession and to the nation. It is well for members to accept the well wishes of their colleagues and friends but membership carries responsibility, not just recognition.

The mission statement of the NAE lists three responsibilities: (1) to advance the well-being of the nation, (2) to promote a vibrant engineering profession, and (3) to provide independent advice to the federal government on matters involving engineering and technology. As Dan Mote is fond of saying, "unlike a professional society, the NAE does *not* serve its members—the NAE *is* the members, and the members serve the nation and the profession." The nation needs a vibrant NAE with involved and committed members and with financial resources to fulfill its role.

The Academy leadership has now approved the next phase of a fundraising campaign to grow its financial resources to meet the three mission responsibilities.

The campaign name, *The Campaign for NAE Leadership in a World of Accelerating Change*, reflects the complexity and urgency of issues facing the nation. Engineering is creating unparalleled economic growth and prosperity and improving the quality of life in many areas. At the same time, there is a growing angst among our citizens and politicians about the future of jobs, individual privacy, and growing inequalities in opportunities and income. To ensure the future, to address problems before they are insurmountable, to anticipate unintended consequences of technological changes, it is critical for us to engage now.

The quiet phase of this campaign started January 1, 2016, and the campaign will end December 31, 2022. The goal is $100M. Five specific needs of the Academy are being addressed. The approach is to lead with strength and to build on successful programs, seeking funding to support strong, action-oriented programs. In a few minutes Dan Mote will the provide specifics for four of these programs. The fifth area of need is the indirect funding that underpins these four along with the funding needed to empower the NAE to fulfill its mission of advice to the federal government. The NAE is too thinly capitalized to support its mission. The campaign aims to fix that.

As many of you know, the Academy does not receive government funding. Over 30 percent of our operating budget is from philanthropic contributions and they are the funds that are used to pay indirect program costs and to cover costs to advise the government on critical issues. There are three sources of funds to cover these indirect costs and to advise the government.

First, the Academy yearly draws a responsible 4.5 percent from an unrestricted endowment that is capitalized at about $40M. Second, unrestricted contributions, largely from members, total another $1.5M. Third, member dues and fees add another $300K. The total for any given year is roughly $3.5M to $4.0M and that creates two insurmountable financial problems. First, the fluctuations in requests for advice are not predictable, while contributions vary year to year. It is therefore very difficult to plan for, execute, and grow programs. Second, the foundation is undercapitalized and the yearly draw of 4.5 percent is insufficient.

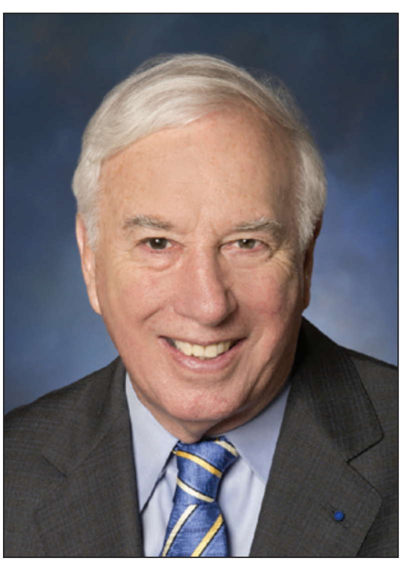
Moreover, the NAE has little capacity to respond proactively to "a big idea" or to quickly react to an unexpected crisis. As such, the campaign goal is to increase the unrestricted foundation by $25M; that is, we will grow that foundation from $40M to $65M so our yearly draw will cover our indirect costs. Funding indirect expenditures is not glamorous but this funding enables all other activities of the Academy. Building this endowment for the NAE will be critically important in the campaign.

The nation needs a vibrant National Academy of Engineering for advice on engineering and change. Through the NAE, engineers and engineering in all sectors of industry, academia, and government can play a role in fulfilling the promise of our profession. The NAE's efforts rest on a platform of unparalleled convening power, the Academy's reputation for integrity, its powerful national brand, and the trust that the engineering community and the government place in our findings and counsel. Relative to universities, industry, and government, the NAE is uniquely positioned to stage initiatives that transcend and inspire these other engineering enterprises.

The NAE is now on the new trajectory of engagement, outreach, influence, and leadership that I talked about last year—and each of you needs to be part of this new future. You will be receiving a communication from Dan Mote suggesting how you can participate in and advance the goals of the campaign.

Thank you for your kind attention, for being with us today, and for your commitment and dedication to the Academy. Enjoy your time with friends and colleagues and enjoy the rest of the annual meeting. It is now my pleasure and great honor to turn the podium over to my very good friend and the leader of the NAE, President Dan Mote.

Times of Accelerating Change Call for the NAE to Change with Them
President's Address by C. D. Mote, Jr.



C. D. Mote, Jr.

Welcome

Welcome to this year's annual meeting of the National Academy of Engineering, and a special welcome to our new members and foreign members on your induction day. I hope that you enjoyed last evening's Great Hall dinner in your honor. We intended it to be one to remember—it is about the best event that the Academy will host for you. That was my experience 30 years ago, and it remains etched in my memory. We do try to create a little magic for you. We are most excited that you are joining us. Welcome too to all members, foreign members, spouses, family and friends, the reunion group, and visitors from home and abroad. I also welcome our anniversary members who are recognized after 25 years of membership and at every 5-year interval thereafter. I am confident that you will enjoy this meeting, plus the opportunity to reconnect with classmates and friends from afar.

Once per year I have this opportunity to present some thoughts for you to consider about our significant plans for moving forward, to highlight an annual meeting theme focused on a current topic that affects all of us, and to present three major NAE awards: the Simon Ramo Founders Award, which is presented this year to **Thomas Kailath** of Stanford; the Arthur M. Bueche Award, presented to **Venkatesh Narayanamurti** of Harvard; and the Bernard M. Gordon Prize for Innovation in Engineering and Technology Education Lecture, which will be presented by **Paul Yock** of Stanford on his Biodesign program.

Our theme for this meeting, "Privacy and Security in the 21st Century – Who Knows and Who Controls," should fill the seats here because it is everyone's concern.

Fortunately, we have two distinguished plenary speakers this afternoon: **Diane Greene** from Google will talk about security of the Cloud and large-scale global data centers, and Mike Walker of Microsoft will talk about personal security with computers, phones, and internet-connected devices. They will clarify for us just how anxious we should actually be. And then at tomorrow morning's forum with the same title, you have a rare opportunity to engage with four expert panelists on this topic: Mike Walker from Microsoft, Lea Kissner from Google, Aanchal Gupta from Facebook, and Batya Friedman from the University of Washington. You will be able to offer questions to them and explore the nooks and crannies of these privacy and security issues. The panel will be moderated and questions handled by our long-time friend, Ali Velshi of NBC News and an MSNBC anchor and business correspondent.

We appreciate greatly the sponsorship for this meeting from Amazon, Facebook, Google, and Microsoft. Their generous assistance makes this program possible. Truly, thank you.

President's Remarks

When I told my wife Patsy that I wanted to share with you some thoughts about the greater implications of accelerating change, her response was "what is that?" Stepping back, I recalled for her the change required to accommodate the systems, services, and apps on her new cell phone and the technician services needed for various updates and breakdowns. Many of you may have thought through the impact of accelerating change already, but I admit that I had not. I find it one of those "onion problems" that gets more deeply rooted and complicated as you peel away each layer.

When we think of accelerating change, technological change first comes to mind, like cell phones. What is new about the current environment is the breadth of changing areas, the speed of their global reach, and the scales of their impacts. New technologies and capabilities are literally changing our world: the internet, cell phones and the disappearance of land lines, biology-based security measures, global connectivity for all transactions, working environments without offices or even home bases, pilotless airplanes and driverless cars, and so on—these changes are coming whether we want them or not. As familiar alternatives disappear, many of us are left simply "hanging on to the lifeboat."

And these tech changes often alter futures that people have spent their lives developing. Or they erase earlier employments from the marketplace altogether and require new talents that the workforce does not have and may never even have heard of. If the impact of the accelerating change is big enough, major workforce disruptions can occur.

I expect that none of this is news to you, but its seriousness is one reason that "accelerating change" occupies our attention.

While technological changes grab our attention first, their implementation stimulates further demands for change to support their consequences, be they social, medical, political, educational, governmental, environmental, judicial, or related to security, exploration, human rights, and other areas. As individuals, each of us grapples with these changes, and we adapt ourselves through what we hope are sound decisions.

What is not as immediately evident is that the same dynamism that individuals experience in adapting to change drives organizations to adapt to change. Hypothetically, while an individual may not be educated adequately for a changed employment demand and require adaptation through additional education, an organization may not meet changed service demands and require adaptation through new systems. So we should expect change for organizations to continue to accelerate, with demands requiring adaptation just as for individuals.

If we look at recent NAE history, we can see this process of changing demands requiring adaptations. Allow me to touch on some of them.

NAE Five-Year Strategic Plan (2016–2020)

In 2015 the NAE adapted to changing times when it created its strategic plan setting forth a five-year vision with six adaptation goals for

i. Membership representation,
ii. Industry collaboration,
iii. Public understanding,
iv. Ensuring engineering talent,
v. Global engagement, and
vi. Effective advising.

There was no change in the original mission of the Academy from 1863. On the contrary, each adaptation enhances the NAE execution of its mission in a world being reshaped by continuing changes.

For instance, consider the first adaptation: membership representation. We aim to increase the representation of business, female, younger, foreign, and underrepresented minority members. This adaptation strives to rebalance the membership to better serve the advisory mission of the Academy.

When the NAE was founded in 1964, the representation was simply that 50% of the membership derived its qualification for NAE membership while employed in business or industry, 40% academia, and 10% "other," which is mostly government. By 2015 the NAE membership distribution was not well aligned with the mission of the NAE to advise any department of government. Accordingly, on the recommendation of the Council, the NAE members agreed to rebalance the membership over a five-year period, with the induction of new members guided in part by these needs for adaptation. The demand to rebalance the membership profile drove an adaptation through new member selection.

In each of the six goals, the demand driving an adaptation is about fulfilling the NAE mission in today's times.

Consider a second example of demands stimulating adaptation.

National Research Council (NRC)

The hundred-year-old National Research Council (NRC), which is the studies arm of the three national academies, has experienced increasing demands by its sponsors and others for its adaptation. While the sponsors continue to appreciate the NRC consensus studies highly, many believe the time required to produce them is too long and the cost too high. Hence, a thorough, independent review of the NRC organization was undertaken in 2017 that has resulted in a plan for extensive restructuring.

The transformation will encompass nearly every operation of the NRC, including the support it provides to over 7,000 volunteers—academy members and nonmembers who serve on study committees and as report reviewers, board members, and content experts, among other roles.

This major organizational adaptation of the NRC is the direct result of accelerating demands from organizations outside the academies, some of which are NRC sponsors and others users of NRC products. Their demands for change likely cascaded down from organizations above them too. This cascade of demand to adaptation passes from and through organization to organization.

Sexual Harassment

Another area of accelerating organizational change is that of attention to sexual harassment, which has engulfed many organizations and sectors around the world, including churches, entertainment, news media, education, government, and athletics, among others. Many organizations have long tolerated sexual harassment by neither supporting adequately the victims of harassment nor sanctioning justly the known harassers. The call for adaptation has been demanding that organizations take explicit actions both to support victims and to control harassers.

A 2018 NRC study sponsored by the three academies, titled *Sexual Harassment of Women: Climate, Culture, and Consequences in Academic Sciences, Engineering, and Medicine*,[1] points to the seriousness of the harassment problem for the individual victims and for the professions too, including engineering. I encourage you all to read this important report, which defines sexual harassment and its impacts. It is freely accessible on the academies website and the opening summary provides a helpful overview of the study's findings and recommendations.

A key finding is the importance of an organizational culture that is, in both appearance and fact, intolerant of sexual harassment through increased transparency, proactive communication, and assertive responses when harassment arises. The perception of an organization's practices on sexual harassment matters as much as its actions. If sexual harassment is perceived as not taken seriously, potential harassers feel emboldened to act without fear of consequences, and victims are intimidated and don't report harassment for fear that no serious attention will result from it, that jeopardy to them personally and professionally will result from reporting it, and that no sanctions will befall the harasser. The victims' perception is that reporting harassment is a lose-lose experience.

In short, organizational policies alone are not sufficient to suppress harassment. The leadership at all levels must communicate and demonstrate that the policies and procedures needed to create a culture that is welcoming to women are taken seriously, followed, and enforced in all cases. As Benjamin Franklin noted, "well done is better than well said."

Based on this NRC study, an op-ed coauthored by study cochair **Sheila Widnall**, committee member **Ed Lazowska**, and me is scheduled for publication in November.

[1] Available at http://sites.nationalacademies.org/shstudy/index.htm.

The NRC's policies on sexual harassment and the adjudication of harassers extend to all individuals participating in NRC activities, which number in the thousands annually.

Closer to home, currently the NAE has no code of ethics for its members. Consequently, the NAE has no mechanism for controlling the behaviors of members who are not employees for any cause.

The NAE Council has initiated a process to establish a code of ethics for all NAE members and others participating in NAE activities. Because the Council is in the initial stages of developing this code, there is nothing more to report at this time, other than to note that the matter is being taken seriously and a proposed code of ethics can be expected. At present the councils of the three academies are considering this matter independently. We expect that all will arrive at similar conclusions.

Sexual and gender harassment will fall under the code of ethics as the 2018 NRC study branded it professional misconduct in faculty-student relations and in the engineering work setting. The leadership of the academies takes harassment seriously and commits the academies to ensuring a welcoming environment for all women.

Again, this is another instance where demand leads to organizational adaptation.

The Campaign for the NAE: Leadership in a World of Accelerating Change

The US government has never provided base financial support for the NAE or the other academies. Funding for individual studies is negotiated with government agencies and others on a study-by-study basis, and costs are only partially covered by foundations. As government funding has been decreasing and foundation support increasing, this deficit financial model creates underfunding for the advice that is the central responsibility of the Academy mission.

The necessary adaptation is to recruit more private support to ensure that the Academy can fulfill its mission in areas where the NAE has leadership and is not, and cannot be, in competition with universities, industry, or the government.

To that end, the quiet phase of a major campaign began on January 1, 2016, and the NAE Council has just endorsed the initiation of the campaign with its announcement today. The academies-wide campaign will conclude on December 31, 2022, with a goal for the NAE of $100 million.

The campaign leads from strength, seeking funding to support strong, action-oriented programs that I call key enablers for addressing major challenges: ***EngineerGirl*** and the **Grand Challenges Scholars Program** for developing engineering talent; **Frontiers of Engineering** for sustaining engineering excellence; the **Center for Engineering Ethics and Society** to ensure the integrity of the profession; and, underpinning them all, funding to **empower the NAE** to fulfill its advising mission.

Empowering the NAE

The Academy relies on real-time support from members to fill the funding gaps in its primary mission, such as unfunded requests for counsel, overhead costs not covered by foundations, and costs of member events and activities. Currently, the NAE has little capacity to respond to "big ideas" or unexpected crises. The underfunded advising mission of the Academy will be front and center in this campaign.

EngineerGirl

Girls need encouragement at an early age to consider engineering—middle school is a turning point. The *EngineerGirl* program provides information to middle school–age girls and their mentors about engineering fields and careers through a website that receives about 50,000 monthly hits by schools and individuals. The Society of Women Engineers collaborates with the NAE in working with girls through the *EngineerGirl* program. Women constitute 60% of the undergraduate student population but only 19% of undergraduate engineering students and 48% of the potential workforce but only 14% of the engineering workforce, among the lowest representations of women by professional grouping. This problem needs serious NAE attention.

Grand Challenges Scholars Program (GCSP)

In the 21st century, the engineering workforce must be prepared for the special demands of global engineering practice to be employable and successful. The Grand Challenges Scholars Program supplements any engineering curriculum by preparing students to engage in any global, socially conscious engineering initiative, including the NAE's Grand Challenges. It is easily adoptable by universities everywhere. More than 100 US universities have or are implementing GCSPs and more than 35 international universities are also doing so. The initial goal is for 200 US and 200 international university GCSPs, and the long-term goal is much larger. More than half the GCSP graduates are women, outpacing the 19% of US undergraduate engineering degrees earned by women. The GCSP transforms any national engineering program into a global one, which accounts for its popularity being driven by the idea.

Frontiers of Engineering (FOE)

The FOE program is the profession's premier networking opportunity for engineering leaders of tomorrow. It provides outstanding early-career engineers with a sense of community and pride in the creative accomplishments of their fellow engineers. The national and international FOE symposia held annually in the US and on a rotating basis in Japan, China, Germany, India, and the EU convene hundreds of selected young leaders on current and emerging topics where they are inspired to build their professional network. Election to NAE membership is highly selective and occurs many years after the FOE experience, yet in 2017 about 20% of new NAE members were alumni of the FOE program.

Center for Engineering Ethics and Society (CEES)

Engineering and technology create jobs and wealth and serve people and society; it is critical that these all occur ethically. Ethical challenges will increase as engineers tackle international and socially complex problems. Ethical practice is necessary to ensure both the integrity of the profession and public trust in engineers and engineering. The CEES Online Ethics Center provides a wealth of information and resources on ethical issues in engineering and technology for engineers, educators, and students, and in 2010 the Library of Congress selected its website for archiving in its historic collections of internet materials, thereby making it available to all through the Library's public website. In 2017 the CEES website had more than 480,000 page views by over 150,000 users in more than 25 countries. A respected center at a respected organization like the NAE provides a critically needed national service.

The Campaign for the NAE rests on the Academy's platform of unparalleled convening power, its reputation for integrity, its national standing, and the trust that the engineering community places in its findings and counsel. None of the campaign goals could be undertaken by universities, industry, or government, and this ensures the goals' independence from competition and their concentration on needs that cut across the entire engineering enterprise. Investments in the NAE will inspire future generations of engineers.

The campaign also highlights the NAE's responses to the demands of both its mission and needed adaptations by raising the private funds necessary to meet those demands and fulfill its mission. In these ways the NAE is preparing future engineers for the benefit of the nation.

Concluding Observations

In times of accelerating change, we should expect that change cascades through people and organizations in a similar manner—with demands leading to adaptations that then lead to demands on other organizations and people, followed by their adaptations, and on and on. The demands on an organization affect its owners, leaders, supporters, employees, contractors, and customers, who adapt and pass down their demands to those serving them. In some accelerating technologies, like communications and information, the scales of demands on the global leaders and competitors and the cascade of adaptations that follow can be very large and even disruptive. It is a consequence of a globally connected world.

Few organizations or individuals are ever free of this demand-to-adaptation cascade for it is created by the recognition of superior advances in the marketplace and of the need for all to adapt while preserving their mission. The NAE is rising to the challenge of the need to adapt with its five-year strategic plan and this major campaign. I'm confident that these will effectively guide the Academy in its adaptations, especially with the thoughtful engagement and generous support of all our members as we address these demands and embrace new opportunities.

Thank you.

2018 Simon Ramo Founders Award Acceptance Remarks by Thomas Kailath

NAE chair Gordon R. England, Simon Ramo Founders Award recipient Thomas Kailath, NAE president C. D. Mote, Jr., and 2018 NAE Awards Committee chair Ray H. Baughman.

The 2018 Simon Ramo Founders Award was presented to Thomas Kailath, Hitachi America Professor of Engineering Emeritus, Department of Electrical Engineering, Stanford University, "for pioneering contributions to diverse fields of electrical engineering and for leadership in technology commercialization and in engineering education, guiding a stellar array of young scholars."

I am very grateful to the Academy for this signal honor, which I owe to the time and efforts of my nominator, Prof. **José Moura**, all those who supported it, and the members of the selection committee. But my greatest debt is to my stellar array of over one hundred doctoral and postdoctoral scholars, whose talents and diligence supported the contributions being recognized today. And I am delighted to note that today one more of them, Prof. **Ali Sayed**, was inducted into the Academy.

While I never had the honor of meeting Dr. Ramo, the first of his many books was of great value to me at a very critical time in my studies. I had the unexpected good fortune of coming to graduate school at MIT in 1957, at a time when few students from India, especially from families with limited means, could even dream of coming to the US. After completing my master's degree in 1959, I was all set to accept a very attractive offer from Bell Labs. But I was persuaded—a nice story for another time—to stay on at MIT for my doctoral work.

One consequence of my late decision was that I had to take the PhD qualifying examinations much earlier than I had expected. In those more leisurely days, the examination comprised eight one-hour written tests. If one did reasonably well on them, one had to face a three-hour oral interview with four faculty members. And as that session progressed, they were surprised to discover, or rather uncover, the shocking fact that I did not know about Maxwell's famous equations of electromagnetic theory. How was that possible?

In India, in those pre-IIT days, one's major, which in my case was radio engineering, was covered only in the final year, after one had completed courses in engineering drawing, workshop, surveying, statics and dynamics, and so on. And we had only one, albeit world-famous, textbook, *Radio Engineering*, 4th edition, by **Frederick Terman** (NAS) of Stanford. Terman was a very notable engineer but, at the time he wrote the book, he did not believe that Maxwell's equations would ever be useful for practicing radio engineers. So of course I failed the examination. However, since my master's thesis had already gained some attention, the examiners kindly decided that I (and another similarly challenged and now famous friend who had failed to explain how steel was hardened) should retake the oral examination, but only after we had successfully served as teaching assistants for the MIT undergraduate course in electromagnetics. In doing so, we found that a very useful resource was a 1944 textbook, *Fields and Waves in Communication Electronics*, written by Simon Ramo and **John Whinnery** (NAS). So thanks in part to Dr. Ramo, I successfully did manage to exit honorably from MIT, in fact as the first Indian-born recipient of a PhD in electrical engineering from MIT. You can imagine my great delight as I stand before you today to receive an award bearing Dr. Ramo's name. I also want to gratefully note here that my time at MIT laid the foundation for all of my later accomplishments. I have the fondest memories of great teachers, research advisors, and a wonderful cohort of fellow students, during what has been called the golden age of information theory.

It probably would be wise for me to stop here, especially at this point in a long afternoon, but I am going to risk venturing a few thoughts on the role of theory in engineering. This is a topic that has always been controversial. Thomas Edison had no patience with theory—and no one can challenge his successes. But I do want to emphasize a very important and not always appreciated point: even very powerful technology can often not be effectively used without a good theoretical underpinning. This became very evident during World War II, when the skills of mathematicians and physicists had to be deployed in order to effectively use several important engineering inventions. In my own career, I changed the major focus of my research roughly every decade and, each time, my students and I found that our success was based on a careful theoretical formulation of the problem at hand.

This brings me to the current buzz about (the new) AI (artificial intelligence), ML (machine learning), CNNs (convolutional neural networks), DNNs (deep neural networks), and similar abbreviations. By taking advantage of vast computational resources to analyze and process billions of bits of labeled data, remarkable and valuable achievements have been made in fields such as speech understanding, face recognition, language translation, and machines that play games such as Go and chess. I am by no means a scholar of AI, but I would like to join in the chorus of many colleagues, including important pioneers, who are concerned about signs of "irrational exuberance." Often, when these technologies are addressed to new problems, such as evaluating job applications or in the criminal justice system, they can lead to erroneous conclusions. And even in already well-explored fields such as computer vision, existing systems can be quite fragile—small changes in the presented data can lead to dangerous errors. I hasten to note that there is a lot of serious work going on to overcome this and other limitations. However, to get a bit technical for a moment, I believe that more theoretical work will be needed to answer questions such as determining the smallest number of layers that a deep neural network will need to achieve a desired level of performance in a particular application. It would be useful to have concepts similar to Shannon's channel capacity in information theory, which defines an upper limit beyond which reliable communication cannot be achieved.

Please indulge me as I try to drive home the value of theory by recounting, with some poetic license, parts of a story entitled "A Matter-of-Fact Fairy Tale" by A.A. Milne, the creator of Winnie the Pooh. Long, long ago, in a big forest, there lived a mighty giant who had agreed to visit a friend who lived 11 miles away. The giant had just acquired the latest high-tech marvel: seven-league boots (this is an English fairy tale: a league is 3 miles, so a single step would take him 21 miles). He quickly strapped them on and strode out toward his friend's house 11 miles away. Of course he badly overshot, and after several further vain efforts, he had to take off his magic boots and glumly trudge to his goal. The problem, as the author explained, was that these were the days before Euclid, so the giant did not know that what he had to do was to construct an isosceles triangle with a base of 11 miles and sides of 21 miles. Theory to the rescue!

Finally, I must gratefully acknowledge the many opportunities made available to me in my adoptive country, with its network of research universities like no other. Over the years, I have benefited greatly from the kindnesses of special teachers and students, research sponsors, colleagues, and friends. My father instilled in me a passion for lifelong learning and from my mother I gained a sense of purpose and determination. While making time for our four children and her many interests and ventures, my late wife Sarah also indulged me enough to enable the career that I have had. And, truly finally, I would like to acknowledge my wife Anu, in the audience this afternoon, who inspires me to keep searching—for fresh adventures and new discoveries.

Thank you all.

2018 Arthur M. Bueche Award Acceptance Remarks by Venkatesh Narayanamurti

NAE chair Gordon R. England, Arthur M. Bueche Award recipient Venkatesh Narayanamurti, NAE president C. D. Mote, Jr., and 2018 NAE Awards Committee chair Ray H. Baughman.

The 2018 Arthur M. Bueche Award was presented to Venkatesh Narayanamurti, Benjamin Peirce Research Professor of Technology and Public Policy, Paulson School of Engineering and Applied Sciences and Kennedy School of Government, Harvard University, "for seminal contributions to condensed matter physics and visionary leadership of multidisciplinary research in industry, academia, and national labs that generated research and engineering advances."

Thank you to the Awards Committee, its chair **Ray Baughman**, NAE chair **Gordon England**, and President **Dan Mote**. I learned that I had received the 2018 Bueche Award in early June. I was at the airport in Hong Kong waiting for a flight to Shanghai when President Mote left me a voicemail message that he wanted to talk. He said it would be "brief and not too painful." I was pleasantly surprised when he told me about the purpose of his call. Thank you, Dan, for this "not too painful" news! I also want to use this occasion to thank you for your considerable past support during my term as foreign secretary. Your championing of the NAE's global role, with sister academies, and the Global Grand Challenges facing society has been, from my perspective, a highlight of your presidency.

It is with deep gratitude that I accept the 2018 Arthur M. Bueche Award. At the time of his passing in 1982, **Arthur Bueche** was senior corporate vice president of the General Electric Company and a member of the NAE Council. I am honored by this peer recognition and humbled when I look at the list of past award winners who embodied Bueche's many-faceted contributions to science and technology policy and to fostering deeper engagement between universities, industry, and government.

After my graduation from Cornell I applied to two industrial labs: Bell Labs, whose origins could be traced to the great inventor Alexander Graham Bell; and GE Labs, whose roots go back to the great inventor Thomas Edison and Edison Electric Co. I did not get an offer from GE, but I did get an offer from Bell Labs—an institution where I spent much of my formative scientific research career, which subsequently led to leadership positions at Sandia National Laboratory, UC Santa Barbara, and Harvard. Each position has broadened my horizons: on the role of national laboratories and research universities in the science and technology ecosystem and on the relationship between technology and society.

At the launch of the engineering school at Harvard in 2007, **Chuck Vest** pointed out in his keynote address that it represented Harvard's recognition that "technology is an integral part of liberal education." Paraphrasing Winston Churchill in a different context, Vest said: "Harvard takes a long time to do things, but eventually does the right thing!" Undergraduate enrollment in computer science and engineering disciplines has increased from 7 percent of Harvard College in 2007 to 20 percent today. Harvard engineers understand not only how things work, but also how the world works. As former president Larry Summers often said, Harvard celebrates both Einstein and Edison.

I stepped down from my deanship of the Harvard Paulson School of

Engineering and Applied Sciences in the fall of 2008 and have since held a joint professorship in technology and public policy with the Paulson School and the Kennedy School of Government. This has allowed me to reflect on lessons learned from contemporary social science and policy research and my own lifetime of practice in science and technology. There are four lessons I would like to briefly share with you.

First, scholars and practitioners of science and technology have largely moved past the once dominant linear model of innovation in which "basic" research is thought to precede "applied" research. Optimizing R&D funding requires connecting scientific inquiry and engineering invention with their applications. These activities are mutually reinforcing and are in harmony, not in opposition to each other. As a historical aside, Vannevar Bush, the legendary science advisor during World War II, popularized the term "basic research." Frank B. Jewett, past president of Bell Labs, was one of his key advisors. Apparently, Jewett was offended by the term "pure" research: Did Bush mean to imply, he wondered, that the research Bell Labs did was "impure"?

Second, history is replete with examples of great engineering inventions—such as the transistor, the laser, MRI, and the solar cell—that led to scientific discoveries. Engineering inventions and scientific discoveries are *both* part of a virtuous cycle that propels broader innovation.[1]

My third observation is that the unity of "basic" and "applied" research activities was a major factor in highly productive corporate R&D activities in the 20th century. Examples abound from AT&T Bell Labs, Xerox, IBM, General Electric, DuPont, and others. For example, when I was at Bell Labs in the 1970s and 1980s, researchers made enormous strides in artificially tailored thin-film materials, which led to scientific discoveries in semiconductor quantum physics. These advances led *simultaneously* to the creation of the high electron mobility transistors that are in every cell phone, and tiny communication lasers that make possible high-speed fiber optic communication across the globe.

My experience at Bell Labs taught me the importance of materials research as a linking discipline, and that one form of research cannot be separated from another. It also taught me that you learn by doing and there is great joy not only in discovery but also when you are able to do what you could not previously do!

Here is the fourth and final lesson I will share. Since my time at Bell Labs, corporate R&D has shifted dramatically toward only those R&D activities that can produce immediate returns. This leaves the public sector with the responsibility to support long-term, mission-focused R&D. It also means that universities and national laboratories must play an even larger role in breaking down the barriers between disciplines and in working on the most pressing grand challenges facing society. In the public sector, this was partially recognized in the 1960s by the Department of Defense research agencies when they created Materials Research Laboratories (MRLs), which were subsequently transitioned to the National Science Foundation (NSF). Under the directorship of **Erich Bloch**, former IBM vice president and the first winner of the Bueche Award, the NSF created Engineering Research Centers (ERCs) and Science and Technology Centers (STCs) in the 1980s. This culture has only recently penetrated the Department of Energy (DOE). In 2009, under the leadership of another Bell Labs alumnus, Secretary Steven Chu (NAS), DOE created Energy Innovation Hubs, Energy Frontier Research Centers, and ARPA-E to bridge the divide between basic and applied research. The other federal mission-oriented research agency, the National Institutes of Health (NIH), has also recognized the need for reform. A recent American Academy of Arts and Sciences study, which I cochaired with Keith Yamamoto (NAS/NAM), strongly advocates for a deeper union between physical sciences, engineering, and the life sciences and medicine via transdisciplinary research.[2]

I want to end my talk with the reminder that progress in any area is critically dependent on people. The nurturing of people is fundamental for research success. An intellectually challenging environment with a high tolerance for failure and long-term, stable funding is required for research to flourish. Recruitment, mentoring, coaching, and the fostering of an egalitarian, meritocratic, open-door culture are essential elements for our future success.

I personally have benefited greatly from the mentoring and sup-

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[1] Narayanamurti V, Odumosu T. 2016. *Cycles of Invention and Discovery: Rethinking the Endless Frontier*. Cambridge, MA: Harvard University Press. Also see references cited therein.

[2] American Academy of Arts and Sciences. 2013. *Unleashing America's Research and Innovation Enterprise*. ARISE II: Advancing Research in Science and Engineering. Cambridge, MA.

port I have received over the years from my teachers, students, and postdoctoral colleagues and staff members in the many institutions I have been associated with. They are so many that I regret that I must acknowledge them collectively. I was also blessed with my parents as role models—my father got me interested in science and laboratory research, and my mother was a very people-oriented person who always showed concern for others. I have had an incredibly supportive spouse for 57 years who has been a guiding force in my peripatetic career. We are blessed with three children and seven grandchildren who are our pride and joy.

Many thanks again to the Academy for this honor!

Highlights from the 2018 Golden Bridge Society Dinner

Ellen S. Weston and James M. Tien with NAE president C. D. Mote, Jr., and NAE chair Gordon England.

On September 30th NAE president **C. D. Mote, Jr.** and his wife Patsy hosted an intimate dinner to celebrate the NAE's most generous members and friends at the spectacular Renwick Gallery of the Smithsonian American Art Museum. Attendees were immersed in "No Spectators: The Art of Burning Man," a collection of large-scale, participatory installations transported from the Nevada desert to the nation's capital. The exhibit captured the dynamic energy of the unique festival and gave patrons the sense of being there. Members enjoyed examining and interacting with the various exhibits.

This year five new Einstein Society statuettes were presented as tokens of the NAE's gratitude for generous support from Jaya and **Venky Narayanamurti** ('92), **John** ('94) and Wilma **Kassakian**, **Ross** ('02) and Stephanie **Corotis**, **James M. Tien** ('01) and Ellen S. Weston, and Julie and **Alton D. Romig, Jr.** ('03).

Two couples were welcomed into the Golden Bridge Society: Teresa and **Steve Zinkle** ('12) and Katherine K. and **John J. Tracy** ('13). Three other new Golden Bridge Society members were unable to attend: **Carl de Boor** ('93), Aliene and **Thomas K. Perkins** ('84), and **Bernard I. Robertson** ('99). Julie and **Alton D. Romig, Jr.** ('03) and **A. Ray Chamberlain** ('06) were recognized as new Heritage Society members. Six members of the Loyalty Society were welcomed: **Bob Loewy** ('71), **Norman Abramson** ('76), Virginia Bugliarello, **Stan** ('91) and Evelyn **Settles**, Jaya and **Venky Narayanamurti** ('92), and Mavis White.

The evening closed with Dr. Mote highlighting the importance of philanthropy in helping the NAE to thrive and to achieve its mission. He expressed his thanks to all attendees for the many ways they give and how much he has enjoyed working with them.

2018 US Frontiers of Engineering Hosted by MIT Lincoln Laboratory

This year's US Frontiers of Engineering Symposium took place September 5–7 at MIT Lincoln Laboratory in Lexington, Massachusetts. NAE member **Jennifer L. West**, Fitzpatrick Family University Professor of Biomedical Engineering at Duke University, chaired the organizing committee and the symposium. The sessions were Quantum Computers: Are We There Yet?, The Role of Engineering in the Face of Conflict and Disaster, Resilient and Reliable Infrastructure, and Theranostics. **Eric D. Evans**, director of the laboratory, welcomed the group to the meeting.

In recent years there has been a dramatic increase in research and financial investment in developing a quantum computer, which theoretically could solve certain problems much faster and more practically than classical computers. A few quantum computational operations have been performed experimentally on a small number of quantum bits, but there remain fundamental scientific challenges to overcome in order to scale up these small quantum systems to large-scale quantum computers. The first speaker in the Quantum Computers session introduced the concept of quantum computing and provided some possible applications. The next speaker focused on quantum algorithms and the power of quantum systems to process information. This was followed by a talk on logical quantum computing, a method of quantum computation based on logic gates similar to classical digital circuits. The session concluded with a presentation on quantum simulation, a type of quantum computer that allows simulation of quantum phenomena that are too difficult to study otherwise.

The next session, The Role of Engineering in the Face of Conflict and Disaster, addressed the important role of lifesaving and community-restoring technologies—from digital, networking, and mapping technologies to those that deliver basic human services in humanitarian crises. An important challenge is ensuring that the technologies in these environments are appropriate for fast-paced and complex situations. The first speaker set the stage by discussing the role of technology from the federal perspective, with a focus on mapping technologies used during Hurricanes Harvey and Maria. This was followed by a talk reflecting on the role of the engineer in society and in the advancement of peace and social justice. The third presenter gave a high-level perspective on technology implementation in disasters with a focus on digital assistance to facilitate cooperation among different types of responder groups. The final speaker discussed USAID's approach to development engineering and disaster relief, describing her experiences with technology implementation in developing regions of the world.

Attendees at this year's US FOE symposium.

Interaction during FOE poster session.

As climate change escalates the possibility of severe weather, infrastructure must be adapted to mitigate against flood impacts and rising temperatures. The session on Resilient and Reliable Infrastructure explored the interconnectivity of water, transportation, energy, and telecommunications infrastructure; how to predict impacts of disaster events; and potential solutions that may be incorporated to upgrade these systems to be resilient and reliable. The first speaker introduced the idea of infrastructure resiliency and discussed how to effectively communicate data science evidence to untrained audiences using advanced web applications with graphic interfaces that make the data accessible and interactive. The next presenter added the critical cybersecurity element and outlined national protection programs that facilitate interface between research and governmental agencies to achieve infrastructure resilience. The final talk demonstrated how implementing state-of-the-art modeling techniques can further understanding of the impacts of both climate change and gradual stressors (e.g., sea level rise) on critical infrastructure.

Theranostics—a system in which multifunctional materials combine elements of sensing, imaging, and/or drug delivery that can simultaneously diagnose/detect disease and provide a means to treat the pathology—was the topic of the final session. The presentations described challenges of developing targeted theranostic nanoparticles and potential solutions, synthetic biomarkers for cancer detection and diagnosis, and immune theranostics, which identifies and quantifies immune cells to better monitor them during immunotherapy.

On the first afternoon of the meeting, a poster session provided an opportunity for attendees to share their research and technical work, allowing them to get to know each other relatively early in the program. On the second afternoon, MIT Lincoln Laboratory arranged tours of its Lincoln Flight and Antenna Test Range Facility, the Lincoln Space Surveillance Complex, and three campus tours that included the Integrated Weather and Air Traffic Control Decision Support Facilities, Wide Area Persistent Surveillance, and Micro Electronics Laboratory.

On the first evening, **Grant Stokes**, division head of Space Systems and Technology at MIT Lincoln Laboratory, gave the dinner speech, "Asteroids—Facts and Fiction." In a presentation that sprinkled interesting scientific data with humor, he talked about the history of asteroid detection, the probability of Earth being hit by an asteroid, and the search for asteroids.

Participants at this year's meeting will be eligible to apply for The Grainger Foundation Frontiers of Engineering Grants, which provide seed funding for US FOE participants who are at US-based institutions. These grants enable further pursuit of important new interdisciplinary research and projects stimulated by the US FOE symposia.

Jennifer West will continue as chair for the 2019 US FOE, which will be hosted by Boeing in North Charleston, South Carolina, September 25–27. The session topics are Autonomous Driving: Technology and Ethics, Engineering the Genome, Blockchain Technology, and Advanced Manufacturing in the Age of Digital Transformation.

Funding for the 2018 US Frontiers of Engineering symposium was provided by MIT Lincoln Laboratory, The Grainger Foundation, National Science Foundation, Defense Advanced Research Projects Agency, Air Force Office of Scientific Research, DOD ASDR&E–Laboratories Office, Microsoft

Research, Amazon, Cummins Inc., and individual donors.

The NAE has been hosting an annual US Frontiers of Engineering meeting since 1995, and also has bilateral programs with Germany, Japan, India, China, and the European Union. The meetings bring together highly accomplished engineers from industry, academia, and government at a relatively early point in their careers (participants are 30–45 years old), providing an opportunity for them to learn about developments, techniques, and approaches at the forefront of fields other than their own, which is increasingly important as engineering has become more interdisciplinary. The meeting also facilitates the establishment of contacts and collaboration among the next generation of engineering leaders.

For more information about the symposium series, visit www.naefrontiers.org or contact Janet Hunziker in the NAE Program Office at JHunziker@nae.edu.

In Memoriam

PAUL G. ALLEN, 65, chair of the board of directors, Vulcan Inc., died October 15, 2018. Mr. Allen was elected in 2005 for contributions to the creation of the personal computer software industry and the development of innovative technologies.

EARL E. BAKKEN, 94, retired cofounder of Medtronic Inc., died October 21, 2018. Mr. Bakken was elected in 1990 for engineering and industrial leadership that transformed his small company, developer and manufacturer of the implantable, cardiac pacemaker, into a worldwide industry.

SAMUEL W. BODMAN, 79, former secretary of energy, US Department of Energy, died September 7, 2018. Mr. Bodman was elected in 2006 for leadership and innovation in materials science and technology and for outstanding cabinet-level service to the US government.

WILLIAM A. CHITTENDEN, 90, retired senior partner, Sargent & Lundy, died August 24, 2018. Mr. Chittenden was elected in 1987 for contributions to the technical advancement of electric power generation and the advancement of professional development in power engineering.

ROBERT R. EVERETT, 97, honorary trustee, MITRE Corporation, died August 15, 2018. Mr. Everett was elected in 1979 for the pioneering of digital computers and their application to real time control systems.

GORDON E. FORWARD, 82, chair emeritus, US Business Council for Sustainable Development, died August 8, 2018. Dr. Forward was elected in 1996 for contributions to technical advances in steelmaking and metals recycling.

EUGENE E. HALLER, 75, professor of the graduate school and Liao-Cho Innovation Endowed Chair, University of California, Berkeley, died June 22, 2018. Dr. Haller was elected in 2010 for improvements in semiconductor performance through contributions to synthesis of ultrapure and doped crystals.

GEORGE N. HATSOPOULOS, 91, retired chair and CEO, Pharos LLC, died September 20, 2018. Dr. Hatsopoulos was elected in 1978 for contributions to classical and quantum thermodynamics, thermionic energy conversion, and industrial thermo-electric energy.

JACOB N. ISRAELACHVILI, 74, professor, Department of Chemical Engineering, University of California, Santa Barbara, died September 20, 2018. Dr. Israelachvili was elected in 1996 for contributions to the measurement and understanding of surface forces in liquids and their application to colloidal, biological, and tribological systems.

CHARLES K. KAO, 84, Honorary Professor, Department of Information Engineering, the Chinese University of Hong Kong, died September 23, 2018. Dr. Kao was elected in 1990 for pioneering and sustained accomplishments toward the theoretical and practical realization of optical fiber communication systems.

WILLIAM M. KAYS, 98, professor emeritus, Department of Mechanical Engineering, Stanford University, died September 9, 2018. Dr. Kays was elected in 1977 for contributions to the theoretical and experimental development of heat exchangers and convective heat transfer, and leadership in engineering education.

GRIFF C. LEE, 91, Griff C. Lee Inc., and retired vice president, R&D, McDermott Inc., died April 3, 2018. Mr. Lee was elected in 1980 for contributions to technical advances in steelmaking and metals recycling.

SHIH-YING LEE, 100, retired professor, Department of Mechanical Engineering, Massachusetts Institute of Technology, died July 2, 2018. Dr. Lee was elected in 1985 for original research on control valve stability, for innovative dynamic measurement instrumentation, and for successful entrepreneurial commercialization of his inventions.

FREDERICK J. MANCHESKI, 92, retired chair, Echlin Inc., died August 1, 2018. Mr. Mancheski was elected in 1991 for leadership in applying the simultaneous design and manufacturing concept to the automotive aftermarket, to achieve in high-quality, cost-effective parts.

ALAN L. McWHORTER, 87, professor emeritus of electrical engineering, Massachusetts Institute of Technology, died July 10, 2018. Dr. McWhorter was elected in 1983 for outstanding research and technical leadership in the fields of quantum electronics and solid-state devices.

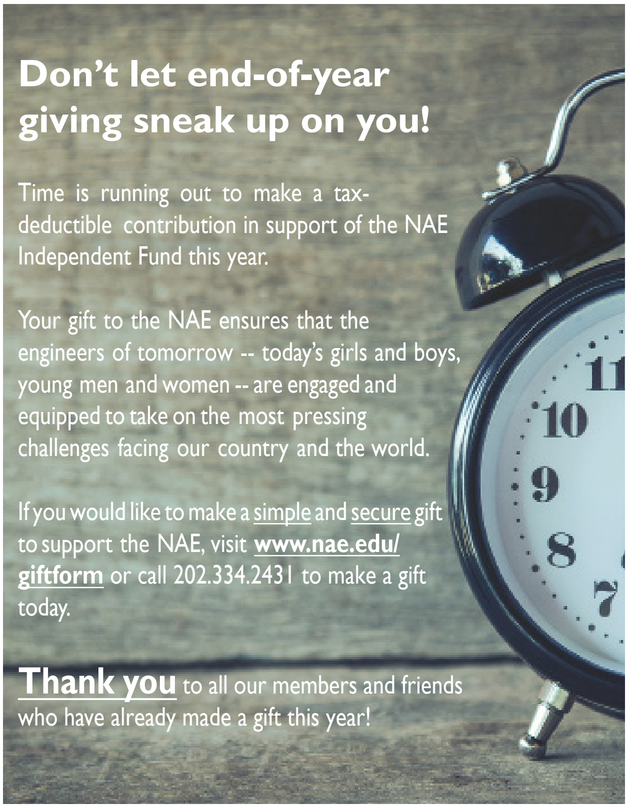
GORDON H. MILLAR, 94, independent consultant, Port Orange, Florida, died November 2, 2018. Dr. Millar was elected in 1975 for contributions to engineering concepts and instrumentation applied to internal combustion engines, and leadership in engineering management and public service.

JUN-ICHI NISHIZAWA, 92, professor emeritus, Tohoku University, died October 21, 2018. Dr. Nishizawa was elected as a foreign member in 2010 for contributions to the static induction devices, dislocation-free semiconductor processing, and optical device technologies.

CAREL OTTE, 96, retired president, Geothermal Division, Unocal Corporation, and consultant, Chevron Corporation, died July 21, 2018. Dr. Otte was elected in 1988 for outstanding pioneer engineering, management, and coordination of exploration for, and development of, geothermal energy.

ROGER W. SARGENT, 91, emeritus professor of chemical engineering, Imperial College London, died September 11, 2018. Professor Sargent was elected as a foreign member in 1996 for leadership in process systems engineering.

JOHANNES WEERTMAN, 93, Walter P. Murphy Professor Emeritus of Materials Science and Engineering, Northwestern University, died October 13, 2018. Dr. Weertman was elected in 1976 for contributions and research on deformation of materials at high temperatures and strain rates and on fatigue of metals.



Calendar of Meetings and Events

November 1–2	Online Ethics Center Expansion Meeting
December 6	Workshop on Engineering Societies' Activities in Helping Align Industry and Academia
December 7–8	NAE Committee on Membership Meeting Irvine, California
December 13–14	Quieter America Annual Meeting: Drones and UAVs
2019	
January 1–31	2019 election of new NAE members and foreign members
January 15	deadline for submission of petition candidates for NAE officers and councillors
January 17	2020 Election Peer Committee Chair & Search Committee Chair Workshop Irvine, California
February 5–7	NAE Council Meeting Irvine, California
February 6–7	2019 NAE National Meeting Irvine, California
February 7	announcement of class of 2019 newly elected NAE members and foreign members
February 20	2019 Fritz J. and Dolores H. Russ Prize dinner and ceremony (by invitation only)
Late February–April 29	call for new nominations for 2020 election cycle (from current members/foreign members only)
March 1–31	election of NAE officers and councillors
March 7	NAE Regional Meeting University of Texas at Austin
March 21–23	German-American Frontiers of Engineering Hamburg
March 28	NAE Regional Meeting Agilent Technologies, Santa Clara, California
April 24	NAE Regional Meeting Illinois Institute of Technology, Chicago
May 1	NAE Regional Meeting University of Virginia, Charlottesville
May 3	NAE Regional Meeting DEKA Research, Manchester, New Hampshire

All meetings are held in National Academies facilities in Washington, DC, unless otherwise noted.

Publications of Interest

The following reports whose authoring committees included NAE members were recently published by the National Academy of Engineering or the National Research Council. Unless otherwise noted, all publications are for sale (prepaid) from the National Academies Press (NAP), 500 Fifth Street NW–Keck 360, Washington, DC 20055. For more information or to place an order, contact NAP online at <*www.nap.edu*> or by phone at (888) 624-6242. *(Note: Prices quoted are subject to change without notice. There is a 10 percent discount for online orders when you sign up for a MyNAP account. Add $6.50 for shipping and handling for the first book and $1.50 for each additional book. Add applicable sales tax or GST if you live in CA, CT, DC, FL, MD, NC, NY, VA, WI, or Canada.)*

Securing the Vote: Protecting American Democracy. During the 2016 presidential election, America's election infrastructure was targeted by actors sponsored by the Russian government. This report examines the challenges arising from that election, assesses current technology and standards for voting, and recommends steps that the federal government, state and local governments, election administrators, and vendors of voting technology should take to improve the security of election infrastructure to ensure that voting is more secure, accessible, reliable, and verifiable.

Susan L. Graham, Pehong Chen Distinguished Professor Emerita, Computer Science Division–EECS, University of California, Berkeley, and **Ronald L. Rivest**, Institute Professor, Computer Science and Artificial Intelligence Laboratory, Massachusetts Institute of Technology, served on the study committee. Paper, $50.00.

Engaging with Human Rights in the National Academy Context: A Resource Guide. The International Human Rights Network of Academies and Scholarly Societies (HR Network) prepared this resource guide based on feedback from participants in the international consortium of honorary societies in the sciences, engineering, and medicine with a shared interest in human rights. The guide illustrates how national academies around the world are engaging with human rights and integrating human rights activities in their work. The guide is available at https://drive.google.com/file/d/1zE7u0XDYru4DObONoteWx9sBFG-z591xU/view.

Ruth A. David, retired president and chief executive officer, ANSER; **John G. Kassakian**, professor of electrical engineering emeritus, Research Laboratory of Electronics, Massachusetts Institute of Technology; **Elaine S. Oran**, Glenn L. Martin Institute Professor, Department of Aerospace Engineering, University of Maryland; and **Elsa Reichmanis**, professor, Department of Chemical and Biomolecular Engineering, Georgia Institute of Technology represent the NAE on the Committee on Human Rights of the NAS, NAE, and NAM.

Understanding the Long-Term Evolution of the Coupled Natural-Human Coastal System: The Future of the US Gulf Coast. The US Gulf Coast provides a valuable setting to study deeply connected natural and human interactions and feedbacks that have led to a complex, interconnected coastal system. The region's landscape has changed significantly because of broad-scale, long-term processes such as coastal subsidence and river sediment deposition as well as short-term episodic events such as hurricanes. Human development, such as levees and canals, buildings, and roads, has also affected the natural landscape. The coupled natural-human coastal system is under further pressure from environmental stressors such as sea level rise, intensifying hurricanes, and continued population growth and development. The resilience and sustained habitability of the Gulf Coast require improved understanding of the coupled natural-human coastal system and incorporation of this understanding in decision making and policies. This report presents a research agenda to enhance understanding, identifies scientific and technical gaps in this understanding, defines essential components of research and development to address the gaps, and develops priorities for research.

Robert A. Dalrymple, Willard and Lillian Hackerman Professor Emeritus of Civil Engineering, Whiting School of Engineering, Johns Hopkins University, served on the study committee. Paper, $60.00.

Graduate STEM Education for the 21st Century. Dramatic innovations in research methods and technologies, changes in the nature and availability of work, shifts in demographics, and expansions in the scope of occupations that need science, technology, engineering, and mathematics (STEM) expertise raise questions about how well the current STEM graduate education system is meeting 21st century needs. In fact, surveys of employers and graduates and studies of graduate education suggest that many graduate programs do not adequately prepare students to translate their knowledge into impact in multiple careers. This report explores how the system might best respond to developments in research on evidence-based teaching practices as well as in the needs and interests of students and society. The report is a resource for stakeholders in the US STEM enterprise—federal and state policymakers, public and private funders, administrators and faculty in higher education, leaders in business and industry, and the students the system is intended to educate.

Subhash C. Singhal, Battelle Fellow Emeritus, Pacific Northwest National Laboratory, and **James M. Tien**, Distinguished Professor and Dean Emeritus, College of Engineering, University of Miami, served on the study committee. Paper, $55.00.

Globalization of Defense Materials and Manufacturing: Proceedings of a Workshop. Emerging economies, social and political transitions, and new ways of doing business are changing the world dramatically. High-value materials-related manufacturing is a key national competitive capability not only in terms of criticality to defense systems but also in relation to technology and knowledge, supplies for other industries, and US exports. This publication summarizes the presentations and discussions at an Academies workshop on materials and manufacturing processes; participants considered changes in the global R&D landscape, DoD and other technology awareness mechanisms, and collaboration models and issues in R&D.

Paul J. Kern, senior counselor, the Cohen Group, and US Army (retired), and **A. Galip Ulsoy**, C. D. Mote Jr. Distinguished University Professor Emeritus, Department of Mechanical Engineering, University of Michigan, served on the workshop steering committee. Paper, $60.00.

Recoverability as a First-Class Security Objective: Proceedings of a Workshop. The Academies' Forum on Cyber Resilience hosted a workshop with presentations from experts in industry, research, and government about the complex facets of recoverability—that is, the ability to restore normal operations and security in a system affected by software or hardware failure or deliberate attack. This publication summarizes the workshop presentations and discussions.

Fred B. Schneider, Samuel B. Eckert Professor of Computer Science, Cornell University, and **Butler W. Lampson**, Technical Fellow, Microsoft Research, chaired the workshop committee. Paper, $40.00.

Opportunities from the Integration of Simulation Science and Data Science: Proceedings of a Workshop. In discussions of the future of cyberinfrastructure for science and engineering (S&E) research, convergence refers both to the combined use of simulation and data-centric techniques in this research and the possibilities for a single type of cyberinfrastructure to support both techniques. At an Academies workshop in May 2018 speakers from universities, national laboratories, technology companies, and federal agencies addressed the potential benefits and limitations of convergence vis-à-vis scientific needs, technological capabilities, funding structures, and system design requirements. This publication summarizes the workshop presentations and discussions.

William D. Gropp (cochair), Thomas M. Siebel Chair in Computer Science, and director, National Center for Supercomputing Applications, University of Illinois at Urbana-Champaign, and **Katherine A. Yelick**, professor and associate laboratory director, Computer Science/Computing Sciences, Lawrence Berkeley National Laboratory, University of California, Berkeley, served on the workshop committee. Ebook, $9.99.

Future Directions for the US Geological Survey's Energy Resources Program. Understanding the national and global availability of geologically based energy resources as well as the environmental impacts of their development is essential for strategic decision making related to the nation's energy mix. The US Geological Survey Energy Resources Program (ERP) is charged with providing unbiased and national and regional assessments of the location, quantity, and quality of such resources and with undertaking research related to their development. At the request of the ERP, this publication considers the nation's geologically based energy resource challenges in the context of current national and international energy outlooks. It examines how ERP activities and products address those challenges and align with the needs of federal and nonfederal consumers of ERP products, and presents recommendations about developing ERP products over the next 10–15 years to inform both USGS energy research and the energy needs and priorities of the US government.

Bridget R. Scanlon, senior research scientist, Bureau of Economic Geology, University of Texas at Austin, served on the study committee. Paper, $70.00.

Review of US Coast Guard Vessel Stability Regulations. This September 2018 TRB letter report reviews regulations and policy documents that establish vessel stability requirements for US Flag vessels. Conducted at the request of the US Coast Guard Office of Design and Engineering Standards, the review considers options to make and keep stability requirements current, align them with international standards, and improve their consistency, clarity, and usability. In addition to identifying promising options for these purposes, the report makes recommendations to the Coast Guard on coordinating with industry advisory groups and collecting, managing, and analyzing data to inform regulatory decisions.

Donald Liu, retired executive vice president and chief technology officer, American Bureau of Shipping, served on the study committee. Free PDF.

Monitoring and Sampling Approaches to Assess Underground Coal Mine Dust Exposures. According to US Energy Information Administration projections to 2050, coal is expected to remain an important energy resource for the United States. Additionally, metallurgical coal used in steel production is an important national commodity. But respirable coal mine dust (RCMD; airborne particles in underground mines) can be inhaled by miners and deposited in the distal airways and gas-exchange region of the lung, causing diseases such as coal workers' pneumoconiosis ("black lung disease"). This report compares and assesses the efficacy of monitoring technologies and sampling protocols used or required by the United States and in similarly industrialized countries for the control of underground RCMD exposure. It offers science-based conclusions about optimal monitoring and sampling strategies to aid mine operators' decision making related to reducing RCMD exposure for underground miners.

Raja V. Ramani, professor emeritus, George H. Jr. and Anne B. Deike Chair in Mining Engineering, Pennsylvania State University, and independent consultant, served on the study committee. Paper, $70.00.

Data Science for Undergraduates: Opportunities and Options. Data science is revolutionizing science and industry alike as work across nearly all domains becomes more data driven, affecting both the jobs available and the skills required. It is imperative that educators, administrators, and students consider how best to prepare for and keep pace with the data-driven era of tomorrow. Undergraduate teaching, in particular, is critical for offering more data science exposure to students and expanding the supply of data science talent. This report presents a vision for the teaching of data science at the undergraduate level, and outlines considerations and approaches for academic institutions and others in the broader data science communities to help guide the ongoing transformation of this field.

NAE members on the study committee were **Laura M. Haas** (cochair), dean, College of Information and Computer Sciences, University of Massachusetts Amherst, and **David E. Culler**, professor, Electrical Engineering and Computer Science, University of California, Berkeley. Paper, $45.00.

Assessing the Risks of Integrating Unmanned Aircraft Systems (UAS) into the National Airspace System. When discussing the risk of introducing drones into the National Airspace System, it is necessary to consider the increase in risk to people in manned aircraft and on the ground as well as the ways this new technology may reduce risk and save lives, sometimes in ways that cannot readily be accounted for with current safety assessment processes. This report examines definitions of risk in the context of integrating unmanned aircraft systems (UAS) into the National Airspace System managed by the Federal Aviation Administration. It also identifies research needs and development opportunities in this field.

George T. Ligler (chair), proprietor, GTL Associates; **Gregory B. Baecher**, Glenn L. Martin Institute Professor of Engineering, Department of Civil and Environmental Engineering, University of Maryland; and **Louis Anthony (Tony) Cox Jr.**, president, Cox Associates LLC, served on the study committee. Paper, $70.00.

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