The Case for Hands-on Education
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To compete in science and technology, a former astronaut says, schools must augment rote learning with exploration and experimentation.

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In the early 1990s, my work as a U.S. Navy Reserve officer and civilian government official regularly took me to the Pentagon. I vividly remember seeing an exhibit there about the life and career of General George C. Marshall. Marshall was the U.S. Army chief of staff during World War II who later, as secretary of state, led the effort to reconstruct Europe that became known as the Marshall Plan. My attention was riveted by one item: an evaluation of Marshall written back when he was a first lieutenant. Near the bottom of the page was a question: “Would you have this officer in your command again?” The colonel who signed this form had checked “Yes,” and had written in, “But I would much rather serve under him.”

It’s such a simple, and yet stunning, remark. Senior military officers are not known for giving gratuitous praise and are never glib about a person’s suitability for command. And indeed, in later years, Marshall would turn out to be an extraordinary leader.

The sound-bite summary of the Marshall Plan makes it seem simple: “The victors helped rebuild the losers.” But the postwar reality in Europe was incredibly complex and, on many levels, terrible to behold. The continent was awash in displaced persons. Manufacturing, banking, and finance systems were shattered; nothing could be grown, produced, or shipped to earn the income that would allow these nations to rebuild. People in many parts of Europe were hungrier than they had been during the war.

Marshall oversaw a large, disparate, and sometimes contentious group of high-powered military officers, business leaders, diplomats, and financiers that included both Europeans and Americans. In their efforts to rebuild Europe and provide an alternative to Communist expansion, they had to develop a level of cooperation and compromise that had never before existed in peacetime. Marshall’s personal temperament and capabilities made an enormous difference. He was a keen student of history, a sharp analyst, and an astute judge of character. Through intense debates and negotiations, messiness, setbacks, and even deceit, he apparently never lost his self-mastery and aura of authoritativeness. Although he kept the
big-picture goal clear, he was comfortable steering toward it when the answers and even the critical questions were unknown. Perhaps most important, Marshall’s service during the war had shown observers, inside and outside the U.S., that his character was beyond question. This high moral standing gave him tremendous leverage, which was essential to developing the plan for European reconstruction.

Marshall’s complex fusion of traits and talents added up to a quality of generative leadership: the ability to bring a group to seemingly impossible courses of action by examining, testing, and overcoming their “mental models”: the deeply held assumptions and biases that hold them back. Generative leaders see — and help others see — that allegedly fixed constraints are constructs of individual and group perception, and not real barriers. This is the kind of leadership most critically needed in businesses and institutions around the world today.

I’ve come to this conclusion after reflecting on my own varied career. Currently, I’m the director of a policy institute, the Battelle Center at the Ohio State University, set up to foster better education in science, technology, engineering, and math (known by the acronym STEM). Before that, I was a science museum director, oceanographer, military officer, and astronaut. Today, science and technology education is often considered a prerequisite for national survival: Any country without a healthy supply of young scientists, technologists, and engineers will not be able to compete in the global economy. But STEM should not just be a way to increase subject matter knowledge and analytic skills for a technological elite; it can help people in all walks of life develop generative leadership skills.

If we truly intend to equip young people to face today’s complex problems and build viable answers, we’ll need many, many George Marshalls. To make this happen, we will have to change the way we approach teaching and learning, and STEM is a good place to start.

The Luck of Learning

I was a lucky kid. Learning was always fun for me. I felt good whenever I figured out or grasped something new. And from an early age, I realized that the knowledge I gained in school would be the key to doing the things I dreamed of doing.

I became fascinated with maps in the second grade, when I had to draw one showing my route to school. From that day forward, I saw maps as my way to learn about places I could not yet explore in person. The early 1960s were exciting times for a young girl with an adventurous spirit. Magazines like National Geographic and Life were...
filled with stories about foreign countries and the people who lived there, and about intrepid explorations of sea and space. I devoured every story and loved to learn how all the technical gear worked.

The great drama of these exploits struck me deeply. Of course, all the explorers of the time were white, male, and much older than I was. But that never registered as a signal that I couldn’t or wouldn’t be allowed to join them. After all, my father was a white male engineer, and I always felt fully a part of his world. I had crawled over his airplane blueprints when I was a young child, and as a teenager I drove the bass boat and flew the airplane just as often as my brother.

My university marine biology and oceanography professors were two of the best teachers I have ever encountered. The oceans were full of wonder to them, and they loved exploration, discovery, and learning. They regularly took students down to the shore and out on the bay, introducing us to marine critters and showing us how to work with field equipment. They shared how they planned their own research expeditions and taught us about the great historical expeditions. These individuals’ lives were full of curiosity, adventure, travel, and learning — just the career model I had been looking for! I quickly changed my major from languages to science.

I was indeed lucky. In many schools, the contrast between “taking science classes” and “being a scientist” is striking — and very sad. Although there are exceptions, far too many kids experience science education as little more than vocabulary lists and isolated facts that they have to memorize. (The number of terms in a typical high school chemistry course exceeds 10,000 — more than are usually needed to learn a foreign language!) Questions are bothersome irritants that a teacher puts on a test, and if you don’t grab the right answers out of your memory bin, you’re in trouble. I’m amazed that we think any student would choose to major in science if this is all they see of it.

But to a dedicated scientist or engineer, a question that hasn’t been answered yet is a wonderful thing. It’s an invitation to let loose your curiosity, draw on your knowledge and understanding, explore and test your ideas, and build — not play back — an answer. For the questions that have propelled me, building answers has always involved working and learning in teams with people who bring varied expertise and background to the table. As you work, you find partial answers, recognize new aspects of the question, and generate new and equally compelling questions. You’ll often discover that you can take action, as George Marshall did, before your understanding of the solution is complete.

This essential work of building answers to new questions turns out to be something that humans do naturally. This is not limited to science and engineering; it’s how we develop from baby to child to adult. It is also a central social process through which economies, societies, and civilizations are sustained.

After college I became an oceanographer. My underlying goal was still to be an explorer: to undertake the type of physical, geographical, and intellectual adventures that had entranced me as a little girl. Then, in the late 1970s, the National Aeronautics and Space Administration (NASA) announced that it needed new astronauts for the space shuttle program. My first thought was, “I could get to see the earth from space with my own eyes!” How could I call myself an earth scientist if I passed up that opportunity? I immediately applied, and joined NASA in 1978 as an astronaut.

The goal of our first year’s training was to gain a solid overview of the agency, the enterprise of manned spaceflight, and the range of roles that astronauts play. We visited all the NASA centers, took condensed courses in every facet of science and engineering related to spaceflight, and qualified to fly jets and to work underwater in simulated weightlessness.

Our program was designed carefully to pass along the experiential knowledge gleaned from the Mercury, Gemini, and Apollo programs. We had in-depth colloquia with the engineers, flight controllers, program managers, and astronauts who made these missions happen. It was so cool to learn, straight from the folks I had watched on television as a girl, what

Generative leadership is the ability to bring people to action by testing and overcoming the biases that hold them back.
the objectives, questions, and issues had looked like to them at the time, and how these had driven mission planning, training, and operations. Every briefing was also a concise case study in how to lead effectively in this complex, dynamic, and highly technical arena.

**Mastery and Moral Authority**

When our first year’s training was over, we started the typical work cycle of an astronaut. For three or four years, we provided technical support to others. Then we trained for a mission. We flew in space. And then we returned to the technical support pool.

This in itself was a crash course in generative leadership. Astronauts get a coveted title, a cool flight suit, and the distinct privilege of flying in space. We are highly visible and, to many, we symbolize NASA itself. The position and all it entails evoke admiration from most folks, but can also elicit envy and resentment from others in the organization. Although we have tremendous responsibility for our individual work and the overall success of any mission we’re working on, we actually have very little formal control. Our ability to get things done stems from mastery and moral authority, rather than from hierarchical power.

The situation reminded me of oceanographic expeditions, specifically the dynamics between the scientific party and the ship’s company. Most of the chief scientists and captains I had sailed with wore their rank lightly and influenced everybody aboard to work together respectfully and constructively to keep the ship safe and conduct our research. But there were scientists who acted as if the crew — with the exception of the captain — were beneath them, and I had seen how the dynamics this created affected morale, scientific effectiveness, and even safety.

As an astronaut, I was now taking on a leadership role on a scale quite different from anything I’d experienced at sea. Over the years, I came to see the leader’s core job as tapping the knowledge and ability of the whole organization while presenting new perspectives that could break through conventional wisdom and reveal a larger spectrum of possible actions. Generative leaders establish a generative culture — stimulating and rich with challenges, and yet safe enough for people to risk taking on sacred cows and exploring new ideas. In 1997, when I became the director of the Center of Science and Industry (COSI) museum in Columbus, Ohio, I had an opportunity to put all I knew about leadership into practice. I was responsible for the daily operations and P&L of an existing science center, the construction of its US$125 million new home, the design of the exhibits and education programs, the business processes and operating systems that the new facility would need, and the completion of a $40 million private-sector fund-raising campaign.

We had a lean staff and a flat organization. Stakeholders included COSI associates, the city’s leading business figures, the mayor, the city council, the governor, and museum visitors. Each person on our core team brought relevant experiences and competencies to the table, but we faced a huge array of challenges unlike anything we had dealt with before. I realized quickly that one of my most important tasks was to ensure that the team was building creative and robust answers to every question.

This in turn meant we had to come to a shared understanding of our situation, tap the knowledge around us, and continually examine and test the answers and solutions we thought we had in place. In other words, we were acting like exploratory scientists, and our terrain was an evolving institution.

As I’ve worked in science education over the years, I have wondered why this type of leadership seems so rare in U.S. schools. This question drew me to collaborate with Karl J. Klimek and Elsie Ritzenhein on the book *Generative Leadership: Shaping New Futures for Today’s Schools*. In the research on the human mind and brain that my coauthors and I conducted for that project, we learned much about the strong relationship between effective leading and effective learning.

According to the classroom-oriented cognitive researchers Renate Numella Caine and Geoffrey Caine, the brain’s natural learning process works most effectively when three elements are present.
The first element is a “high challenge/low threat” environment. People learn most effectively when they feel fundamentally safe but sense something novel or unknown. The low threat level allows the primal centers of the brain to relax; if a threat is perceived, these survival circuits will overwhelm and shut down the brain regions involved in learning. The stimulus — be it novel experience, curiosity, need, or the desire for a result — keeps the brain’s major processing centers alert and highly active.

Second, people learn best in an environment that is rich in diverse sensory information: imagery, spoken words, written text, numbers, and hands-on activity combined. This variety stimulates multiple regions of the brain simultaneously, strengthening the signaling pathways between them. Further, since each individual has a unique blend of learning aptitudes, richly orchestrated experiences are more likely to engage a broader array of people, whether schoolchildren or adults.

Finally, real learning occurs through the active processing of new information to their own personal experiences can catalyze this kind of processing very well.

I saw in these three elements the ingredients that had made my own learning experience so powerful. At COSI, we incorporated them into the design of all our exhibits and education programs. I also realized the need to bring them into formal education, especially STEM education.

**Out of the Factory Model**

Even after years of education reform efforts and the world-shaping impact of computer technologies, many schools are stuck using an education model based on the factories and armies of the 19th century. Authority is hierarchical; knowledge is broken down into discrete, specialized, unrelated units; and the day is divided into manageable blocks of time.

Perhaps this is efficient for auditing resources, tracking time, and verifying that people (including the teachers) are following the rules, but it’s not a recipe for an effective learning environment. Learning is an inherently generative process; our schools need to be generative environments, which in turn requires generative leadership.

One major part of the Battelle Center’s research agenda focuses on a small set of schools across the country that operate in a generative fashion, and that appear to have greater potential to develop “answer builders” than do typical public schools. These “STEM schools” are emerging through the efforts of private foundations, state governments, and corporations, often via initiatives where all of these very different entities operate in a collaborative network to design, launch, govern, and sustain the school.

One good example of such an initiative is the Metro High School in Columbus, Ohio. From the highest levels of leadership involved in its design phase to its current operations, Metro is a fascinating model of network management and generative leadership. The school arose through the efforts of the Battelle Memorial Institute (the global research and development nonprofit that sponsored the Battelle Center), the Ohio State University, the Educational Council of central Ohio, and a well-known network called the Coalition of Essential Schools (whose principles influenced us profoundly). These organizations created the school through a generative design process in which the leaders (starting with the presidents of Ohio State and Battelle) carefully built a network of mutual trust and collaboration, holding firmly to their collective purpose even during difficult and messy stages.

Metro doesn’t focus on science or math to the exclusion of literature, history, or the arts. Instead, the big idea behind the school is establishing STEM as a set of skills, disciplines, and habits of mind that will serve a student well in any field of study and help him or her grow into a citizen ready for any walk of life. In other words, Metro is fostering the same generative process of “building answers” that was common to George Marshall’s leader-
ship in European reconstruction, flight operations leadership at NASA, and my own work at COSI.

Some people equate self-directed, project-based programs like Metro with a lack of rigor. They think that science education should emulate the high-pressure rote learning systems found in many Asian societies, which produce a high number of young engineers. But some experts on the Asian model point out that although these students may be schooled soundly on factual knowledge, their capacity for creativity and innovation has often not been developed.

I agree with this, and I saw the difference firsthand when I studied in Norway during college. I was amazed by the superlative memory my classmates had for technical particulars like the chemical composition of minerals. I worried about my ability to excel until we went on a field-mapping exercise in Scotland. Our professor strode over to a huge black chunk of rock, pointed to a small white rectangular object within it and demanded, “What is that?” None of us knew. But whereas my classmates seemed paralyzed, I knew how to build an answer: with clear and careful observations, sharp reasoning, testing, and further observation. Within about five minutes, I had an initial hypothesis: An inclusion, or piece of foreign rock, had been caught up in the black rock when it was molten and transformed by the heat. I could outline the observations and tests that would be needed to confirm this and I could describe the detailed mineralogy needed to flesh out the story.

The Metro School is just two years old, but it’s already become a model for other schools. And, of course, there are other inspiring models, and innovative networks of schools, in existence today. But in general, education seems stuck right now. So many stakeholders seem stuck in battles over curricula, financing, governance (public versus private), and accountability. Parents, policymakers, and educators can’t even agree on what schools need most: more knowledge, passion, and creativity? Or stricter rules and regulations? And all the discussions seem to presume a choice that is either/or. We overlook the possibility of involving everyone in articulating the core purpose and values of the education system as a whole.

General Marshall led Europe and the United States through complex and perilous terrain to a solution that transformed the Western world. I suspect the ultimate solution to today’s challenges in U.S. education (and perhaps education elsewhere) will require similar leadership and perseverance. We need leaders in education and business who can really listen to one another, keep a clear focus, and who can move forward authoritatively, despite everything around them being dynamic, messy, and not entirely controllable. We need the kinds of schools that naturally help people to become generative leaders and learners, especially in science and technology, because we need more George Marshalls.