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Teaching Entrepreneurship to Engineering Students

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"IMPORTANCE OF ENTREPRENEURS TO THE U.S. ECONOMY"

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Entrepreneurs make critical contributions to our nation's economic development. They bring technology intensive, often risky, innovations to he commercial market - and in the process, even help to develop whole new industries.

In fact, the *Economist* probably said it better: "America gets more than half of its economic growth from industries that barely existed a decade ago..."

So how do we define entrepreneurs?

Entrepreneurs are risk takers, implementers, rule breakers, adventurers; or in a word: innovators.

And there's no question that innovation is the heart of economic progress. Innovation is the very bones and sinew of our economy and society. It enables us to compete in the global marketplace, raises our prospects for more productive and satisfying lives, and strengthens our national security.

Innovation moves forward hand-in-glove with the fresh science and engineering knowledge that drives it. Discovery and innovation will be twin pillars of 21st century progress. They bring with them the potential for an era of breathtaking transformation.

But innovation is not an abstract force. It's what people do to drive change. Innovators break the "rules." It may be a leap of faith to trust them, but trust them we must, or we suffer the quagmire of the status quo.

New ideas, like all revolutions, alter the fabric of society... that is, if the ideas are realized. Innovators, those who apply knowledge to tasks that are new and different, who turn ideas into reality, keep us fresh and moving forward. An idea lying fallow does not an entrepreneur make.

With this as a backdrop, I would like to examine two questions today. The first is, what is the essence of innovation: what attributes do innovators and entrepreneurs exhibit? The second, and equally as important, is how do we encourage innovation?

Inspiration is a key characteristic of innovation in our country. In the United States, we have admired and been enchanted by inspired entrepreneurs. Life magazine cited our most famous inventor - entrepreneur, Thomas Alva Edison, as the peak achiever in the last millennium. This non-stop "idea-to-reality machine" beat out queens and kings, scientists and mathematicians, writers and artists in the Life magazine competition. The "Wizard of Menlo Park" was number one in a list of a hundred leaders and thinkers that included Elisabeth I, Sulleyman the Magnificent, Galileo, Mary Wollstonecraft, Pablo Picasso, Helen Keller, and Albert Einstein.

Born in 1847, Edison radically changed global society by transforming electricity from a novelty to a household and commercial necessity. Talk about being an entrepreneur! Edison cleverly garnered a critical investment from a group of Manhattan movers and shakers by inviting them to his home and lab for a weekend. Underlying his stellar record of over a thousand patents was his belief and often quoted adage, "Genius is one percent inspiration and 99 percent perspiration."

In both science and engineering, there is a lot of perspiration in the carry-through, but the spark comes from the inspiration. Inspiration is that chaotic and complex moment where past and present knowledge combine to synthesize an idea that stands on the edge of the future. Imagining something is where it starts.

If our goal is to teach entrepreneurship to engineers, then encouraging them to use their imaginations, to be visionaries, and to think creatively is critical.

Since the dawn of civilization, there have always been some people whose thought process directed them to see things through another lens. These thinkers become triggers in society to propel us in completely new directions with their over-arching vision. These people are the "envisioners" - those who see a scenario for the broad application of new knowledge.

The renowned physician and writer Lewis Thomas hit the nail on the head when he said, "Discovery consists of seeing what everybody has seen and thinking what nobody has thought." Similarly, our nation's management guru, Peter Drucker, when asked several years ago how he predicted so well said, "I never predict; I just look out of the window and see what's visible but not yet seen."

Einstein believed that "imagination" was the key to his work. He said, "Imagination is more important than knowledge." Imagination in the hand of entrepreneurs brings the ability to connect the results of research to society, i.e., to envision. The ability to understand the larger context in which we work - the sector, the society, and even the time in history, the moment in civilization, is crucial to any form of entrepreneurial leadership. Learning to read the larger context provides a path for imagining the future.

As engineers, part of our task is to mentor others in scanning the big picture for the relevant signals. We must develop acumen for such thinking in our students. We

cannot graduate talented engineers with supremely specialized expertise that exists in a vacuum. The ability to read the subtle signals will often make the difference between being the industrial leader or laggard. Reading the tealeaves, so to speak, is not just for mystics anymore. It's a job for mentors, managers, entrepreneurs, and every kind of leader.

The astute "readers of the context" and imaginers of possible futures have proven to us that envisioning is a worthwhile endeavor. Envisioning combined with risk-taking is a supercharged combination on the personal level as well as on the level of the economy.

The Austrian economist, Joseph Schumpeter, developed a rule-breaking theory of economics in the 1940s in which he described a "creative destruction" of industrial cycles. As Schumpeter described it, a normal healthy economy was not one in equilibrium, but one that was constantly being disrupted by technological innovation.

According to Schumpeter, disruption is the normal state of a healthy, vibrant economy. Of course, such a state can cause losses in its path. In fact, the disruption caused by an innovation can sometimes be painful, while simultaneously creating new opportunities for growth. For Schumpeter, this "creative destruction" is the engine of technological innovation.

The trick to turning the process into success is having a rational hand on the tiller, with a capacity to perform no matter how the frontier may move.

Something new and exciting is happening in the 21st century that can help us foster this capability. The borders between discovery, learning, and innovation are blurring. Increasingly, scientists and engineers, educators, and entrepreneurs are working across many different disciplines and fields and in different sectors to make the connections that lead to deeper insights and more creative solutions.

We look ahead to exquisite but practical improvements in everything from drug delivery systems to renewable energy resources. I like to think of this as "creative transformation" - the flip side of the coin of "creative destruction." Focusing on creative transformation can help us act intelligently as we move ahead. It can cultivate a benevolent approach to robust change. Nowhere is this more evident, for example, than in the emerging field of nanotechnology.

This is one of several territories that the National Science Foundation has identified as directions that have over-arching potential within our discovery-at-the-frontier investment portfolio. Nano is one of five capabilities that help to connect and recompose core science and engineering disciplines. As we look to the near future, we know that engineers will create a vastly accelerated, technological horizon. They will be the primary developers of the nano revolution.

It was a brief twenty odd years ago, with the invention of the scanning/tunneling electron microscope, that we could first observe molecules on a surface. Now our micro world is becoming a nano world.

Nanotechnology gives engineers the ability to manipulate matter one atom or molecule at a time. They will be able to make a wish list of qualities and characteristics to build into a new material or machine. The power of this capability to work at scales three orders of magnitude smaller, will transform engineering, manufacturing, and society itself.

Add to this, the potent future of terascale computing – computing technology that takes us three orders of magnitude beyond prevailing computing capabilities - and we will literally remake what we know as engineering.

When we combine the speed and breadth of terascale computing and the minute dexterity of manipulating the world at the nanoscale, we get a glimpse of fiction that becomes our future.

This is more than exciting; it's fantastic! This new world, however, will require not only a different education for engineers, and for engineers as entrepreneurial leaders, but also for engineering educators.

When we bring to bear another capability, cognition, to this already powerful mix, we are moving toward "shimmering insight."

The dictionary defines cognition as the mental process by which knowledge is acquired. Most of us would simply say, this is learning. Learning is the foundation territory of all other capabilities, human and institutional. Our understanding of the learning process holds the key to tapping the potential of every child, empowering a 21st century workforce, and, in fact, maintaining our democracy.

Because of new tools and interdisciplinary research investments, our understanding of the learning process has changed dramatically in the past two decades. A rich knowledge base in cognitive science has been developed jointly by linguists, psychologists, philosophers, computer scientists, engineers, neuroscientists, and others. This has prompted NSF to create Science of Learning Centers to pursue more formally how people think and learn.

By focusing on cognition, we will advance our capability in everything from teaching children how to read, to building human-like computers and robots, to understanding how organizations work, and soon. Industry can capitalize on this knowledge in training initiatives, in the manufacturing process, and in the development of new products. But, fundamentally we will help empower people, and thus empower the nation, all of which can lead to wealth creation, and social progress currently unimaginable.

To nano, tera, and cognition, we add two very different ways of seeing -complexity and holism. These act as two sides of the same coin to guide us in the best way to use our accumulated knowledge of science and technology to discover new knowledge and better understand how to use it.

Mitch Waldrop, in his book Complexity, writes about a point we often refer to as "the edge of chaos." That is, "where the components of a system never quite lock into place, and yet never quite dissolve into turbulence either... The edge of chaos is where new ideas and innovative genotypes are forever nibbling away at the edges of the status quo..." This territory of complexity is 'a space of opportunity,' a place to make a marriage of unlike partners or seemingly disparate ideas.

Holism is the "flip side" of the complexity coin. Holism and complexity have a symbiotic relationship. Complexity teaches us to look at places of dissonance or disorder in a field as windows of possibility. Holism teaches us that combinations of things have a power and capability greater than the sum of their separate parts.

Holism is far from a new idea. We have seen it work in social structures since the beginning of civilization. Something new happens in this integrative process. A singular or separate dynamic emerges from the interaction.

When we educate students to think about complexity and holism as two sides of a coin, we develop a pattern or attitude to search for the disordered fringes of a field and to pick out fragments of possibility. With these pieces of potential, different 'wholes' can be created in new integration. The possibilities are endless.

A key social arrangement to synergize these five directions could be a partnership. A trusted partnership may be the most flexible and supportive structure for arguing about ideas to forge results.

Partnerships bring to the table participants with different expertise and resources, and a diversity of perspectives. As our products, processes, problems and solutions continue to increase in complexity, our need for a diverse combination of partners will grow as well. Partnerships must always be flexible to reshape and regenerate in order to stay fresh with the momentum of ideas.

At NSF, we actually have a program called Partnerships for Innovation, which seeks to foster major partnerships between the public and private sectors. We want to link broad-based scientific and engineering knowledge, garnered through research at the frontier in our universities, with the talent of local communities across the country.

The lead institutions in NSF's Partnership for Innovation Program are selected to act as catalysts in helping their surrounding communities transform merit-reviewed, research-derived knowledge into innovations that create opportunities for new wealth and a broader economic base.

Now that we've traveled the multifaceted nature of innovation and entrepreneurship, we need to examine how to keep the process moving forward.

We need to educate today's engineers and tomorrow's future entrepreneurs to think strategically and holistically. They need to be able to read patterns and trends from the larger context to envision the future. Integrative, cross-boundary-educated, visionary engineers are critical components to success in our age of complexity.

We need to educate our engineers beyond their technical expertise. The best technical training must be combined with understanding how that expertise fits into the larger societal environment, into our overriding national goals, and indeed, into the goals of other nations.

Today, the trend in science and engineering research is much more cross-boundary centric. Many disciplines are converging in surprising ways to generate the new knowledge needed for the increasingly complex challenges we face as a society.

Engineers and scientists must be able to see functionally beyond the boundaries of their disciplines. After all, nature knows no disciplinary boundaries. In the past, when the tools for discovery and application were rudimentary, innovative progress across the frontier of science and engineering was possible only by parsing the frontier into doable pieces named disciplines. But today's increasingly exotic tools allow more holistic attack along the frontier.

Today's engineering graduates must be capable of integrating knowledge from a variety of disciplines and working with industry partners to advance that knowledge into innovations. In the larger sense, innovation depends upon a mutual, synergistic set of interactions that includes not only science, engineering and technology, but social, political and economic interactions as well.

We need new arrangements that foster the kind of integration that supports innovation, and the social and economic well being it enables.

If innovation is at the heart of progress, then we need to understand the skills that foster the capacity for risk taking, for imagination, and a tolerance for unfamiliar and uncertain territory. That in turn will mean that our institutions must evolve to engender these skills.

Innovation and competitive entrepreneurship will always remain an enduring quest, an on-going process. There is no peak that we can reach that will assure continuing success. It is not a matter of sticking to the task for the long haul. It is the "haul."

We will always need to keep improving the process with fresh ideas and a fundamental commitment. We will need to break the right rules and take the right risks. It will be demanding, exciting, and a bit precarious, as the unknown always is.

Entrepreneurs will have to be effective collaborators, innovators, risk takers, and communicators, working across shifting boundaries, and embracing diversity. They will need to know the human and social dimensions of technology; for example, how technology can be shaped to suit our needs, as well as the parameters of decision-making. Our social and economic progress depends upon it. All of you will carry the responsibility and the excitement to make it happen over and over with the following fundamentals in mind for you to contemplate.