
# Educate to Innovate: Factors That Influence Innovation: Based on Input from Innovators and Stakeholders

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# Educate to Innovate

## Factors That Influence Innovation

### Based on Input from Innovators and Stakeholders

Prepared by:
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and
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In cooperation with the
National Academy of Engineering
and the
University of Illinois at Urbana-Champaign

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James Duderstadt, president emeritus and University Professor of Science and Engineering, University of Michigan

Karan Watson, provost and executive vice president, Texas A&M University

Although the reviewers listed above provided many constructive comments and suggestions, they were not asked to endorse the opinions or conclusions of the authors nor did they see the final draft of the publication before its release. Responsibility for its final content rests entirely with the authors.

# Foreword

Robust innovation in the United States is key to a strong and competitive industry and workforce. But America is facing an innovation challenge. To remain a leader in the global marketplace, the United States must significantly enhance its innovation capacities and abilities among both individuals and organizations. Innovation capability should be a new indicator of US workforce readiness to compete successfully in the global economy.

A new educational paradigm is needed to help current and future American workers remain competitive. Corporate and national educational strategies should create opportunities for students and workers to develop their ability to innovate. Academic environments, from the earliest ages through continuing education, can be improved—and even designed—to enhance this ability. Universities, in particular, should be leaders in the drive to improve US innovation. Companies also have a role to play, through thoughtful attention to their culture, inclusiveness, and workspace design as well as partnerships with local schools and universities.

The aim of the Educate to Innovate project is to expand and improve the innovative capacity of individuals and organizations by identifying critical skills, attributes, and best practices—indeed, cultures—for nurturing them. The project findings will enable educators in industry and at all levels of academia to cultivate the next generation of American innovators and thus ensure that the US workforce remains highly competitive in the face of rapid technological changes.

C. D. Mote, Jr.
President
National Academy of Engineering

# Contents

# 1

# INTRODUCTION

> The first step in winning the future is encouraging American innovation. . . . What we can do—what America does better than anyone else—is spark the creativity and imagination of our people.
>
> *– President Barack Obama, 2011*[1]

Innovation is widely heralded as the key to successful competition in the increasingly global economy. How is the United States preparing its students and workers to innovate and excel in the new economy? What skills and attributes need to be nurtured? Is it even possible to educate to innovate?

Until recently, many doubted whether entrepreneurship could be taught. Now research on the qualities and experiences of successful entrepreneurs is being translated into entrepreneurship education programs at universities and businesses around the country. It is conceivable that the same can—and indeed should—be done with innovation.

The National Academy of Engineering (NAE) organized the Educate to Innovate (ETI) project to answer these questions, drawing on the experiences and observations of dozens of innovators and input from stakeholders in large and small business, university-level academia, and K–12 education. This monograph presents an analysis of interviews with 60 innovators and insights from expert discussions at a workshop to identify the skills and attributes, experiences, and environments that contribute to innovators' development and success.

## PROJECT OVERVIEW

Efforts to improve the capacity of individuals and organizations to innovate must be a high national priority to ensure that the United States remains a leader in the global

[1] President Barack Obama, State of the Union Address, January 25, 2011.

economy. US universities already excel at teaching the basic sciences, engineering, and technologies that are essential for innovation. But, although several university programs focus on entrepreneurship, which helps translate inventions into marketable products and services, very little education focuses on innovation.

Starting with the premise that innovation can be taught or nurtured, the Educate to Innovate (ETI) project was established to "help identify and assess skill sets critical for innovation, and explore best practices for inculcating these in US-based students of engineering, science, mathematics, and technology." Charles M. Vest, then president of the NAE, appointed a steering committee for the project and presented it with a twofold task:

1. **Pre-workshop study:** Provide guidance to a research team at the University of Illinois at Urbana-Champaign (UIUC) that will interview a select group of successful American innovators and ask them to reflect on their education and careers and identify the skills, experiences, and environments that contributed to their becoming successful innovators.
2. **Workshop:** Design and organize a workshop at which the results of the pre-workshop study and other relevant research and perspectives are presented and discussed with a view toward identifying best practices for inculcating these skill sets and experiences in students of engineering, science, mathematics, and technology.

The project began with 60 semistructured, open-ended interviews with US innovators. Digital recordings of the interviews were transcribed and qualitatively analyzed to identify attributes common to several innovators. The workshop, held October 22–23, 2013, at the NAS Building of the National Academies in Washington, DC, brought together 56 innovators and leaders from various fields to share insights on innovation and its education.[2]

## PRE-WORKSHOP STUDY: INTERVIEWS AND ANALYSIS

US innovators were interviewed in open-ended conversations (by phone, video, or in person) that ranged from 30 minutes to two hours. The innovators have distinguished themselves in diverse fields; they include professors, researchers, engineers, innovation authors, artists, entrepreneurs, venture capitalists, and technical and business leaders of small and large businesses.[3] The interview questions were designed to elicit narratives of personal experiences and perspectives on success in innovating and on factors that contribute to that success.

The interviews were audio-recorded, transcribed, and reviewed by the interviewees for accuracy. The project team then used a qualitative data analysis program to identify

[2] The workshop methods and demographic profile of the interviewees are presented in appendix A.
[3] Brief biographical notes on the interviewees are in appendix B.

themes that were common among the responses and significant to the participants and thus distilled factors that contribute to the success of innovators.

The study findings were discussed and elaborated at the workshop.

## WORKSHOP

The workshop brought together 56 stakeholders—including 23 of the interviewed innovators—representing large business, small business, academia, and K–12 education to examine the interview results and consider ways to enhance education to better prepare students to be innovative.[4] The perspective of large businesses is relevant because they typically run internal programs that foster innovators; on the other hand, small businesses typically do not have programs devoted to innovation and yet have led to several innovations. Academics play the dual role of being innovators and being responsible for preparing future generations of innovators. The influence of childhood experiences and environments in the success of innovators is the domain of K–12 educators.

Four breakout groups convened in three successive sessions with the following tasks:

- Session I (90 minutes): Discuss the preliminary analysis of the interviews, address the assigned question (the four questions are listed below), and prioritize the skills, experiences, and environments identified in the innovator interviews.
- Session II (60 minutes): Identify "takeaways" from the first session and consider what else the workshop participants would like to learn from the interview analysis.
- Session III (90 minutes): Discuss next steps based on the discussions in the first two sessions and identify road blocks, points of leverage, and specific stakeholders.

The questions assigned in session I were posed by the steering committee to advance the discussion beyond the findings from the pre-workshop study:

1. Are innovators different from entrepreneurs and intrapreneurs? How best to build natural bridges between innovation and entre-/intrapreneurship?
2. How can individuals learn to transition from their own innovation capacity to group/team innovation capacity? How can this capacity be further extended to open innovation environments?
3. In academic and federal research, merit review is the holy grail. But merit reviews and taxpayer dollars often fund conservative ideas. What are the best ways to train graduate students to be innovative in this environment?

[4] The workshop agenda is in appendix C and the list of workshop participants in appendix D.

4. What are the criteria for the best paradigm(s) for innovation education? What new elements need to be considered in such education?

For the first session the groups were heterogeneous in their composition to enable cross-sector knowledge exchange; group members' backgrounds and interests were considered in forming these groups. For sessions II and III, the groups were reorganized by sector so that participants could bring what they had learned from the exchange of perspectives in session I and collaborate to identify sector-specific takeaways and next steps.

## ORGANIZATION OF THE MONOGRAPH

Chapter 2 presents the keynote and plenary presentations from the workshop, offering overarching perspectives on the subject. Based largely on analysis of the interviews, chapter 3 provides definitions of *innovation* as distinct from *entrepreneurship* together with some defining characteristics of innovation. Specific skills, experiences, and environments that contribute to the success of innovators are described in chapter 4, drawing on the observations of both the interviewees and the workshop participants. Chapter 5 presents key discussions, "takeaways," and suggested next steps based on the guided discussions in the three breakout sessions at the workshop.

# 2

# Setting the Stage

The workshop began with three talks that set the stage for the discussions to follow.

At the evening reception before the workshop, **Herbert Holden Thorp**, provost of Washington University in St. Louis, spoke on "Building a Culture of Innovation and Entrepreneurship in Higher Education." He stated that universities can play a significant role in educating for innovation and thus promote economic development. At the same time, it is important to understand a university's limitations. Local communities may expect universities to spawn startups; such expectations have to be recognized and managed. Universities don't really have venture capital, and if they are averse to risk they will be less inclined to support faculty- or student-led startup efforts. Universities need to plan and strategize based on the amount and type of risk they can accommodate.

Thorp also emphasized the value of integrating different fields/areas/communities in the university environment. For example, social entrepreneurship is important to universities, so social and technical entrepreneurs should work collaboratively. And in teaching, professors and alumni entrepreneurs should be teamed to bridge the gap between those worlds. He cited the University of North Carolina's Center for Entrepreneurial Studies (a component of its MBA program), but cautioned against "burying" entrepreneurship education in the business school.

In closing, he called for broadening the entrepreneur concept to social entrepreneurship and reiterated the value of team teaching to ensure cross-disciplinary engagement.

The following morning Steering Committee Chair **Arden L. Bement, Jr.**, director emeritus of the Global Policy Research and Global Affairs Office at Purdue University, opened the workshop with a reminder of the national importance of innovation, quoting President Obama in a 2009 speech on the economy[1]:

[1] These remarks are cited in the report *A Strategy for American Innovation: Driving Toward Sustainable Growth and Quality Jobs* (National Economic Council, 2009); available at www.whitehouse.gov/administration/eop/nec/StrategyforAmericanInnovation. The complete speech is available at www.washingtonpost.com/wp-dyn/content/article/2009/08/05/AR2009080502067.html#.

> The United States led the world's economies in the 20th century because we led the world in innovation. Today, the competition is keener; the challenge is tougher; and that is why innovation is more important than ever. It is the key to good, new jobs for the 21st century. That's how we will ensure a high quality of life for this generation and future generations. With these investments, we're planting the seeds of progress for our country and good-paying, private-sector jobs for the American people.

The most rapid and long-term returns accrue when innovation is integrated with the education and training of graduate and undergraduate STEM talent, but the United States can do much better by specifically focusing on educating the future workforce to be innovative. Bement said that the power to innovate lies in everyone, and that academic environments can be designed to enhance this ability in their students by fostering a culture of creativity and innovation, points made by a number of the interviewed innovators.

As entrepreneurship programs become globally ubiquitous, the United States will need to ensure superior capacity to innovate to maintain its leadership in the global economy.

**C. D. Mote, Jr.**, president of the National Academy of Engineering, described his "Vision for Universitywide Innovation and Entrepreneurship." The primary goals are to *inspire and value* and to emphasize *education and practice*.

Mote began by noting that solutions to the country's most critical problems depend on innovation and entrepreneurship (I&E) and that both types of endeavor enhance research. He made the case that universities have a role in supporting such endeavors by developing a culture of I&E and outlined broad steps to guide universities in this area:

- make I&E education and practice a *signature feature* of the *entire* university, create a culture everyone can be part of;
- develop I&E *education* and *practice* initiatives spanning the university;
- create a hybrid *center for innovation and entrepreneurship (CIE)*, partly decentralized and partly centralized; and
- put some *money* into it.

Innovative thinking should be an expectation of the university community and all students should be exposed to it early in their university experience, through a variety of educational formats and delivery methods. Mote articulated inputs and outputs for CIE *educational programs*.

Inputs entail courses and modules on business, entrepreneurship, communications, law, creativity, and innovation provided through degree programs, experiential education, industry mentors, partnerships, and internships. Mentoring, counseling, and consulting services that facilitate innovation and entrepreneurship are necessary CIE responsibilities; in fact, Mote cited mentoring as absolutely critical, and good mentors and access to them integral for the successful implementation of this vision.

Outputs would be measured by degrees/certificates, efficacy in business, and entrepreneurial skills, and recognized in the commercialization of ideas, the development of business plans and industrial partnerships, and competitions, challenges, and prizes. Achievement measures are critical to monitor progress and success.

CIE *practice programs* should be designed to support technology transfer, industry-university agreements, new venture creation, and startup activity. They should be characterized by centralized services, research, development of business plans, and mentoring and vetting. Outputs can be measured in patents, licensing revenues, formal/informal industry relationships, the hiring of student inventors, the number and financial success of startups, and jobs created.

Universitywide participation in innovation and entrepreneurship should be inspired, supported, and welcomed. CIE services and programs would be accessible to all campus units, not specific to a single unit.

Mote presented examples of such programs at the University of Maryland, where he was president from 1998 to 2010. Based on his experience, he offered specific recommendations for a university-based center for innovation and entrepreneurship:

- It should be a point of contact for I&E education, tech commercialization, and venture creation, with a convenient, central location on campus. Incorporating existing university services, the CIE should build and support a culture of I&E, with, for example, the capacity for licensing and "prospecting." Centrally integrated services, where possible, will minimize redundancy, enhance quality, and, most importantly, increase access.
- The university should create a signature hybrid design for I&E, to encourage and celebrate innovation and entrepreneurship, produce value (e.g., patents, licenses, and ventures), and adopt best-in-class ideas. Ensuring that the university community understands intellectual property and related issues (e.g., patents, invention disclosures, licenses) is a CIE responsibility.
- The wider community should be considered in terms of both impacts and engagement. The center should capitalize on its location and engage pre-university and other community partners as mentors, teachers, students, employers, and investors.
- The CIE director should report to the university president, operating through an executive committee and guided by both an external and a university advisory council. At the University of Maryland the external advisory council brought community visibility. Achievement measures for the CIE investment are required, together with benchmarking and regular updating.
- The starting point for such plans would be conversations to introduce the I&E vision to the university, development of business and implementation plans, and determination of budgets and timelines. Such conversations must be led by the president, who is the only person who can "clear away the brush" that can get in the way of a smooth transition to this new paradigm.

In summary, universities should brand themselves as a place for innovation, help create new enterprises, facilitate the transfer of knowledge and technology beyond the university, and make a determined effort to make intellectual property protection less onerous.

The workshop concluded with a plenary session that featured reports from each breakout group and a presentation by **Thomas Kalil**, deputy director for technology and innovation in the White House Office of Science and Technology Policy. He stressed the importance of encouraging students to set and meet more ambitious goals, giving them greater autonomy, connecting them to real-world problems, and involving them in designing courses and university programs, including collaborations with external partners. Established programs such as the NSF Innovation Corps (I-Corps) program and NAE Grand Challenge Scholars Program can serve as models. He also suggested developing case studies and playbooks based on the successful models. Beyond this workshop and resulting monograph, he called for additional products such as a report making a strong case to various stakeholders to invest in programs designed to educate to innovate. He closed by mentioning the opportunities around open educational resources and the importance of organizing them to inspire students and get them excited about working on difficult problems.

# 3
# What Is Innovation?

A key task for the project team was to define *innovation* and to understand its relationship with *entrepreneurship*, terms often used interchangeably.[1] Drawing from the interviewees' comments, this chapter articulates the distinction and linkage between innovation and entrepreneurship, followed by a more detailed characterization of innovation.

## EXPLORING THE RELATIONSHIP BETWEEN INNOVATION AND ENTREPRENEURSHIP

There was general agreement on a first-order distinction between *innovation* and *entrepreneurship*: *Innovation* creates societal value (through an existing or new product, process, or service), and *entrepreneurship* involves realizing the market value of an opportunity, not necessarily an innovation, by making it commercially or socially viable.

> I use a garden analogy sometimes. You plant a garden and you can grow these beautiful vegetables and fruits, but if you don't have a plan for harvesting those and getting them to market and realizing the value that you've created, then they just rot in the field. I think that's what happens with a lot of innovation. There's great innovation that's done without a plan for how to actually realize the value from that innovation. But can you have entrepreneurship without innovation? Absolutely, because . . . you can realize value from [opportunities] without having to create that value through innovation.
>
> —*Tom Miller*

A number of interviewees and workshop participants viewed entrepreneurship as a way to bring an innovation to market. Jack Hughes put it this way: "an entrepreneur

[1] In this report, the term *entrepreneurship* is used to capture both entrepreneurship and intrapreneurship.

is someone who sees the potential of an innovation and decides to take the risk to bring it to market."

Some innovators felt that innovations can lead naturally to entrepreneurships. Dean Chang explained his view on why it is important to focus primarily on innovation.

> It's really important to lead with "innovation" and have it evolve into "entrepreneurship" because innovation is the large end of the funnel that appeals to and actually requires participation by a much broader audience. Nonbusiness, nonengineering, and non-STEM people are every bit as important to include in that innovation process because the process is not as rich and has inferior outcomes without that diversity.
>
> *– Dean Chang*

Yet another perspective relating innovation and entrepreneurship is that entrepreneurship is one way of innovating, i.e., entrepreneurship itself can lead to an innovation. Innovation in this entrepreneurial style is done "in the context of a startup—that is, finding the customers and gathering resources in an entrepreneurial style [and innovating] while solving the problem," according to Robert Metcalfe.

Amy Salzhauer cautioned that not all innovations can stand by themselves and lead to entrepreneurial ventures. Typically, a successful entrepreneurial venture brings together *multiple* innovations. She explained: "I don't think [innovation and entrepreneurship] necessarily go together. [People ask me to] comment on what they hope to put into place for their innovations out of their academic lab. But most innovations are not stand-alone companies. They don't qualify for entrepreneurship that follows them all the way through the course of their lifecycle, but they might really do well to be licensed by an existing company or brought together with lots of other technologies to try and build something new. So I find that [how to create an entrepreneurial venture from an innovation] a fraught question, because [the innovators] have hopes that they're just going to start a lot of companies and a lot of money will come in, and statistics don't bear that out."

In summary, although both innovation and entrepreneurship are focused on "value," they differ fundamentally in that innovation focuses on its creation while entrepreneurship focuses on its commercial or social realization. Not all innovations lead to an entrepreneurial venture and not all entrepreneurships are based on one or more innovations. Figure 3-1 illustrates the various associations between innovation and entrepreneurship.

## DEFINING INNOVATION

Perspectives about what constitutes innovation vary, but the 60 interviews revealed common features, illustrated in Figure 3-2. The innovators understood that innovation can result in a physical product, a process, or a service that impacts society in a timely manner; it must have impact in the present or near future, because unless the

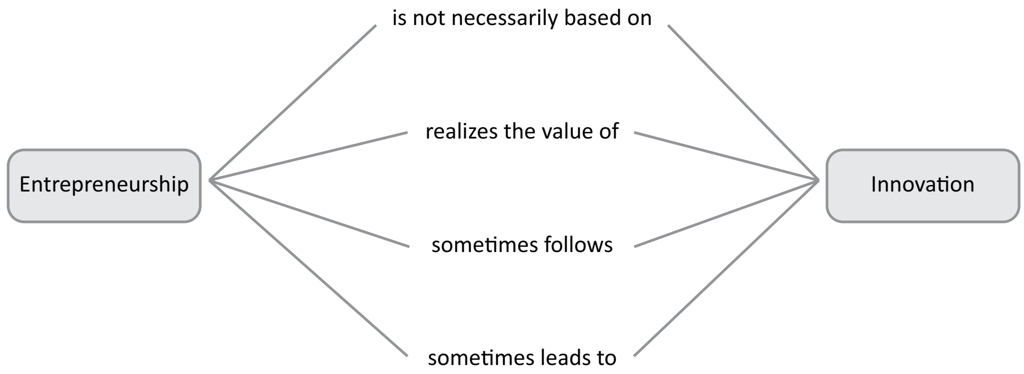


FIGURE 3-1 Different ways of relating and differentiating innovation and entrepreneurship.

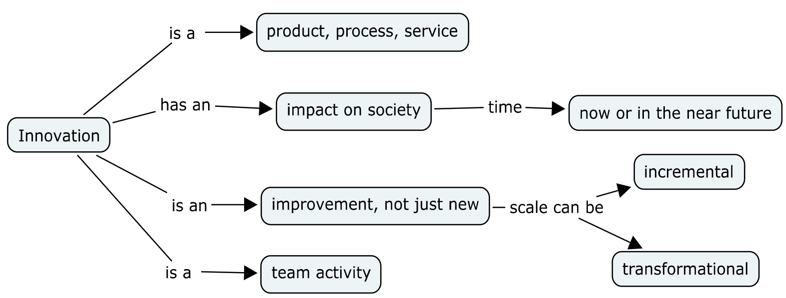


FIGURE 3-2 Characteristics of innovation.

impact is realized, it is not an innovation. Finally, innovations effect some improvement (beyond the creation of something new) and this improvement can be incremental or transformational.

Thus, the following characteristics of innovation emerged from the innovators' comments:

- Innovation provides societal value
- Innovation is an improvement.
- Innovation occurs at the interfaces of different disciplines.
- Teamwork is important to the process of innovation.
- Innovation is part of an invention-value continuum.

## Societal Value

The interviewees felt strongly that innovations must provide societal value. In the words of Ashifi Gogo, "Innovation should be helpful to society—it's great if one makes a discovery, but it's even better if the discovery can be used to improve individual lives directly as we work to improve humanity's state of being around the world."

Part of the value of an innovation is linked to timely adoption—it should be useful in the near future. In fact, as Chad Mirkin clarified, unless the innovation is actually used by society, it cannot be called an innovation: "Once you decide that you have a technology that can impact the masses, then you have to ask 'Where am I today and how far do I have to go for me to be able to do that?' If the answer is 'With a year and $3 million worth of funding,' then that's very reasonable if the market size is big. If the answer is 'In 60 years, maybe, with half a billion dollars' worth of funding,' you're probably too early, and that is not an innovation!"

R. Graham Cooks cautioned innovators against deceiving themselves into believing that everything they do is socially meaningful or useful: "An innovator is this two-headed kind of a personality where you've got a cowboy on the one side who is unearthing new stuff, and on the other side you need to be careful that it's not self-deception. In other words, if you feel that you have some penchant for innovation, then the big danger is that you'll convince yourself even in cases where the work is trivial or doesn't have the implications that you hoped it would have."

Robert Dennard agreed: "Lots of inventions aren't innovations. I have 62 patents, and only one or two are actually being used, and if it's not used, it's really not innovating very much. So innovation's a breakthrough, something that's really useful and it doesn't have to be patentable, even."

### Improvement

Innovations are typically viewed as "something new." However, all the interviewees and workshop participants emphasized that innovations are improvements, not necessarily just new.

Laurie Dean Baird explained her approach to discern the value of an innovation: "If I look at something that's new and ask 'Is this innovative?' then I ask 'How was this problem solved before? What was the industry standard and how is this different?' And if the answer is that, in addition to being new (the problem or solution), it takes the hassle out of something (i.e., it improves life), then it is innovative."

> I don't see innovation being the introduction of something [that is just] new. There are many things new every day, and I wouldn't say they all are innovative. I think to be innovative, something has to be better than the predecessor product, materially better, not just a small percentage better.
>
> *–Tim Cook*

In terms of the scale of improvement, innovations can be transformational—for example, creating large-scale changes in the way technology is used or thought about. Mary Lou Jepsen said, "I think of innovation as doing some transformative work in an area or in a combination of areas that trail blazes in a way that people recognize has moved the ball forward . . . in a way that is a leap."

But it is not necessary that every innovation be groundbreaking or dramatically change the world. Bernard Meyerson referred to "continuous innovators": "The danger is there are other types of innovators that are just as necessary, what I call the continuous innovators. These are the guys who come to work every day and make it 5 to 10 percent better, and there's a terrible undervaluation of that."

### Innovation at the Interfaces of Different Disciplines

Innovators in all the areas represented—academia, large companies, small businesses, and the arts—agreed that innovation occurs at the interfaces of disciplines and requires the synthesis of knowledge from different fields. Yo-Yo Ma captured this aspect using the concept of the edge effect from ecology: "If you think about where new ideas can come from, you need proximity to density, and if you're at the edge of something you see both sides; you already see over the wall. You could be part of one ecosystem, but you actually are constantly interacting with another ecosystem, and so you see the possibility of what another ecosystem can bring. And . . .  if the center uses the knowledge at the edge, the center does benefit."

Chapter 3 provides more detail about the impact of interfaces of disciplines on developing and enhancing an individual's innovation capacity.

### Teamwork

Innovation is the result of teamwork, a point often made by the innovators. And it depends on the work of the team as a whole, not the work of one key innovator and other "supporters." Ivan Seidenberg observed: "I get comfort in knowing that life is cumulative, innovation is cumulative, it's not individual. Let's take some of the greatest examples: Let's start with the example everybody's using right now, and I knew him well. Steve Jobs is a genius, but he didn't invent the computer; he didn't invent anything that went into the iPhone, but he made it all work together . . . so what did he invent? Take another example: Bill Gates had enough common sense and enough vision to know that PCs couldn't talk to each other, so he built operating systems to make them talk to each other, but along the way, they didn't work very well when they first came out with them. They (Jobs and Gates) needed a full team and with their superior insights and innovative spirit they made something bigger than any one person could have made. So all I'm getting at is that there's really no one innovator who can innovate all alone. I can't think of any one person that gets it all right. Is there anybody? Is there anybody in the literature that gets it right the whole time?"

Chapter 3 deals with the importance of teamwork for innovation in more detail.

### Innovation in the Invention-Value Continuum

Innovation is part of a continuum between invention and value. Innovators may start with an invention and then innovate to create value from it, or start with a problem and solve it innovatively.

Innovation was described as the application of inventions to real-world needs. It can also be driven by the concept of marketability or trying to solve a problem. As Robert Fischell said, "Sometimes we see an invention and then we can apply it to another thing, but that doesn't happen very often. Most times, we hear about something and it occurs to us that the way they're doing it is not good, and so we innovate a better way."

John Rogers characterized innovation in the context of technological and market factors: "it is often difficult to describe innovation as strictly one thing or another. It is very much a blend of technology push and market pull in terms of how the innovation is done, especially around completely new classes of technology."

## CONCLUSION

Analysis of the 60 innovators' observations revealed that innovation is an improved product, process, or service that benefits society in a timely and, sometimes, transformational manner. It is a team activity at the intersection of different fields, bringing together diverse ideas, abilities, and/or methods to result in the creation of value.

The next chapter examines what defines and helps shape the people who become successful innovators.

# 4

# Skills, Experiences, and Environments That Contribute to Innovation: Analysis of the Interviews

Based on evaluation of the interviews, the project committee determined particular skills and attributes, experiences, and environments that contribute to successful innovation. Workshop participants then considered these lists and elaborated on them. Dwayne Spradlin called for casting the net wide when seeking to promote innovation and find innovative solutions:

> I think we do all of the bright, creative, inventive people out there a disservice by trying to find reasons to deny that they are innovative. I also think that we create a mindset that only certain people or organizations are capable of innovation, and in so doing, we're actually building social and institutional structures that have their own kind of elitism to them. Innovation comes from everywhere. We need to tap every person and the entire globe to find innovative solutions to the most difficult problems we have.

Innovator and entrepreneur Anoop Gupta concurred and drew on his own experience to illustrate the point: "I think everybody can be innovative. I think it is some combination of intrinsic abilities and the environment. Several successful innovators in Silicon Valley have come from different parts of the world and might have not even thought of innovation in their home countries. We came to Silicon Valley, and suddenly all of us are innovating and starting companies. So, environment matters a lot, but does that make everyone equally innovative? I think the basic upbringing and work ethic also matter a lot. For example, is drive the same in everybody? Everybody is not the same, even in one environment."

This chapter presents the specific factors that contribute to innovation, complemented by apposite quotations and observations from the interviewees and workshop participants. The factors are listed separately, but there is constant interplay among them and their nature or influence can change.

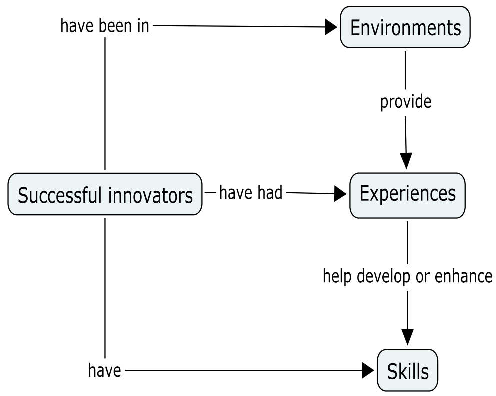


FIGURE 4-1 Factors that contribute to the success of innovators.

While it is commonly accepted that innovators have certain skills that have made them successful, this study also focused significantly on understanding how they obtain those skills. Accordingly, a new framework for factors that influence the success of innovators has been developed (Figure 4-1). It captures the interplay between skills, experiences, and environments as fundamental to the success of innovators. In general, environments provide experiences and these experiences enhance or develop the skills of the innovators.

It should be noted that the following lists of skills and attributes, experiences, and environments are not necessarily exhaustive. Indeed, during the first breakout session at the workshop, participants were asked for their ideas about elements missing from each list; these discussions are presented at the end of each section. Furthermore, it is important to understand that interpreting these categories as a whole, rather than as discrete components, will provide the greatest understanding of the factors that influence the success of innovators.

## SKILLS AND ATTRIBUTES

Certain skills and attributes were repeatedly mentioned by the interviewees as contributing to their success as innovators. Although they are examined individually, skills were often discussed as part of a collection of factors that contribute to successful innovation, each of which may fuel or depend on another. Some of these characteristics may be perceived as innate, but many participants felt that they can be nurtured by educational programs.

When asked to think about the skills and attributes that contributed to their success, the interviewed innovators cited

- creativity,
- dissatisfaction with the status quo,

- intense curiosity,
- the ability to identify serendipitous moments,
- willingness to take risks and to fail,
- passion,
- knowledge of their field,
- the ability to identify good problems/ideas,
- the ability to work at the interfaces of disciplines, and
- the ability to sell an idea.

### Creativity

Being creative was considered fundamental to innovation. The interviewed innovators generally agreed that some form of creativity is necessary for, and enables, innovation and entrepreneurship. At the workshop, participants similarly noted the necessity of creativity for invention, innovation, and entrepreneurship.

According to Ryan Bailey, "I think you can be creative without being innovative, but it would be hard to be innovative without being creative." KT Moortgat described creativity as "the ability to think about the world in new ways, thinking from a clear, open perspective. It involves thinking de novo, and somehow leveraging historical or existing solutions, without being encumbered by them."

Some innovators considered innovation and creativity synonymous, viewing the exercise of creativity as having a useful purpose. To Prashant Jain, it is natural to think of being innovative as being creative, because "you may not be creating anything tangible, but in the process of even creating new information, you're being innovative. Even that—creating new knowledge or information—is innovation."

Rodney Mullen mused that the value of creativity is in unhindered intuitive thinking without worrying about the result, and innovation is the next step in which creative effort is blended with a sense of purpose. He explained it this way:

> When I talk about creativity, I think of just that, of throwing yourself into no-man's land and hoping to see and feel what tracks, what sticks together at an intuitive level, and just to untether and go with it. It doesn't matter; you're not even looking for a result, because at that stage you just get anxious and will end up going to what's already been done rather than diving into what could be. . . . The next step, after you get things to stick together, is to get the sense of the broader sort of movements you have now created, then you start to go around and you look at things embedded in the natural environment that can combine with what you feel is beginning to work—context, shape, and content. How can I project it onto something broad where it will fit? . . . *That* is innovation.

Yo-Yo Ma cited conditions that influence creativity, such as a "collaborative spirit," which he said has energy of its own that is fueled by curiosity as well as flexibility. Imagination, or the sense of possibility, also plays a central role in the creative process.

> In terms of creativity, I think there are three values that precede innovation. The first one is collaboration, and this is not like I'm teaching or you're teaching; we're teaching and learning at the same time. You say "Guess what I found?" "What did you discover?" Then you're immediately sharing, and that I think leads to a kind of curiosity that leads to a kind of flexibility in thinking, because I'm opening myself to your world, you're opening your world to me. Curiosity is the second value. The collaborative spirit is leading to a kind of energy of its own, curiosity, and the more curiosity there is, the more you have the ability to imagine. Imagination is the third value, because imagination is obviously required in any form of innovation. You have to be able to sense that "Oh, this could be possible," or you could just do things blindly and hit on it, but then if you don't have the imagination to see the reality of something that's happened, you don't recognize that that innovation has taken place.
>
> *–Yo-Yo Ma*

## Dissatisfaction with the Status Quo

Innovators usually are dissatisfied with the status quo and willing to challenge it. In Tim Cook's words, "Innovation requires not being satisfied with the status quo, almost an individual that's never satisfied, a perfectionist."

David Hornik contends that innovators get frustrated when they encounter problems and constantly think about how to improve everything they encounter in their daily lives and "the fact that people are not making it better, and so they see lots and lots of opportunities to make the world a better place, and they envision ways in which to do it."

As an artist, Jad Abumrad characterized innovation as a blend of the positive feeling of creation and the negative feeling of being disgusted with the status quo: "I think innovation might be as much a frustration and a disgust with the ordinary or status quo as it is some sort of positive longing for what could be."

## Intense Curiosity

Intense curiosity is a hallmark of successful innovators. "I think a very intense curiosity is key [for innovation]," said Tim Cook, who added that "Curiosity can be very broad. It's 'How does something work? How does someone think?' Curiosity in many ways is a 'How?' [rather than a 'What?']. I think it's hard to teach curiosity, but I think you can give things to encourage it. I don't think you can get there with a course, I think that would be the wrong approach, but I think you could do a lot with the environment. . . . I think my underlying state as a person has a curious foundation in it, and so that probably helps, but I do think the environment heavily influences curiosity."

People who are curious tend to be observant of new ideas, concepts, or situations and associate them with something else they've learned and take advantage of serendipitous situations. Jack Hughes described his own experience, associating curiosity with serendipity: "Your eye gets caught by something while you're working on something, or you remember something from the past and then the opportunity presents itself; I think serendipity is more a function of . . . a general curiosity."

Curiosity also helps the innovator overcome the fear of asking a "bad" question. Ivan Seidenberg said, "[I am curious] and was never driven by any sort of closet fear that I would look dumber; little kids are curious, and they have no fear of asking a 'bad' question."

### Ability to Identify Serendipitous Moments

Serendipity plays an important part in innovation. It may be loosely perceived as luck or chance, but the innovators agreed that serendipity results from acute observation and the ability to take advantage of those moments. Aaron Koblin put it this way: "Life is about setting 'luck traps'; nobody's lucky, but luck is happening constantly all around us, and some people see it and some don't. I think the idea of serendipity may be more about watching for these opportunities than it is about some cosmic property." And as one workshop participant said, the more you know, the more luck you are likely to have.

While being attentive to serendipitous moments, it is important to also remain honest about what the facts are. Alyssa Panitch cautions that "part of the ability to be innovative is really to always pay attention to what the data is telling you and to not read into the data what you want it to be." She credits her mentors in science for teaching her this "good science" principle of "listening" to one's data.

Paul Camuti also said his education contributed enormously to his ability to handle serendipity. Although he is not currently doing traditional engineering work, he draws on what he learned in his undergraduate studies: "I have learned rapid problem solving and analytics. The stress of an engineering undergraduate education and the rigor of applying analytics really is something that I use every day, and I think that that applies to the moments of serendipity. There's not an idea that comes up that you don't try and, as we say here, rack and stack. 'Is this good or bad? Where would it apply? How well would it apply?'"

Others felt that the US education system does not prepare its students to look for or take advantage of such moments. One reason for this, according to Tim Cook, is that education is "largely too formal, too predictable, too planned, too regimented, too routine." Franz Aliquo extended this characterization to life in general: "Life is really built to make you ignore those serendipitous moments . . . to stick with a predetermined path instead of noticing these weird things that are happening on the periphery. . . . I learned to overcome it the hard way by noticing the various streams of life and having to select those that were most appropriate for me."

### Risk Taking

Innovators are commonly viewed as risk takers who pursue endeavors knowing that there is a chance of failure. A number of the interviewed innovators commented on the utility—and even the necessity—of failure. They are not afraid of or deterred by failure and they accept and manage it as a part of their work, learning from it and moving on.

In fact, according to discussants at the workshop, innovators may not see themselves as risk takers, instead approaching their endeavors as an adventure or challenge, associated with fun or enjoyment, or a calculated risk to be confronted and eliminated, and focusing on the risk/reward ratio in which the reward outweighs the risk. Failure then becomes an opportunity for learning, again offsetting the perception of risk.

> There's a big difference between encouraging failure and discouraging fear of failure. The really big wins, from an innovation perspective, are often risky and uncertain. You can't tell if you're going to succeed or fail when you start. You have to build and be unafraid of failing on the other side. You don't have to like failure, but in order to get the big win, you cannot fear it.
>
> *– Regina Dugan*

David Agus echoed Regina Dugan's comments: "you have to figure out a way to really encourage risk taking. To me that's everything."

Andy Walshe talked about the importance of distinguishing between perceived risk and actual risk: "We need to differentiate the perceived level of risk versus actual risk. If the perceived risk is much higher than the actual risk, it provides for good training opportunities as long as the difference is not so great that it causes the person to 'freeze' or lose the ability to learn from the situation. If the perception of risk is low but the actual risk is high, then the results can be catastrophic. In our business this is when people get hurt or killed. High performers are 'masters of risk.'"

At the same time, the innovators cautioned against blind acceptance of failure, which could lead to experimenting for the sake of experimenting. Ivan Seidenberg clarified: "There's a lot of books written about 'Well, you've got to fail five times to succeed once,' and I [fear that] it creates a negative atmosphere in that you get a big group together, like a big company with a lot of people, and you end up with a false focus on experimentation for experimentation's sake because someone wrote a book and said failure is a good thing. . . . A great [innovator or innovative] company does both, meaning that they experiment, fail, and invent, and that failure is not celebrated as a symbol of the innovative spirit if the results are absent."

Acknowledging the value of the ability to manage risk and encouraging risk taking is a significant challenge in academic, social, and professional environments. In the words of Bernard Meyerson, "the biggest challenge [in educating to innovate] is getting people to buy into taking risk. The single biggest impediment I found in large companies, particularly, is that they don't tolerate risk particularly well. Put another way, if you miss your quarter's numbers, you're fired."

### Passion

Every successful innovator has passion—an intense, compelling desire and enthusiasm—to make a change. Passion is also linked to motivation, curiosity, and the willingness to take risks and be persistent in one's endeavors. It may even be indicative of an individual's capability to innovate: Passion motivates a person to do hard work, and, according to John Hennessy, is one of the distinctions between "successful [innovators] and smart people."

Andy Walshe said that having passion for one's pursuit buffers the emotional impact of failure and helps an innovator persevere in the face of failure. In his words, "[If you are not passionate], the failures can beat you down pretty quickly, and you'll revert back to . . . the safer and usually more conservative approach." Part of the innovative process therefore involves assessing one's level of personal interest in a project, which may ultimately affect the success of the project.

It is also important to balance passion with reason. In discussing what he looks for in potentially innovative job candidates Jad Abumrad explained, "I would look for a certain kind of relentless, obsessive unease, but there is also something in [successful innovators] where they are relentless but they are also infinitely flexible, and it's a bit of a paradox, really."

### Field-Specific Knowledge

Innovators have a deep understanding of the basic principles of their field, including experiential and/or technical knowledge. For example, to innovate technologically, "you must begin with a comprehensive knowledge of science and engineering," said Robert Fischell. In addition, Robert Metcalfe suggested that innovators should be able to answer the question, "What do you know that nobody else knows about this problem?" He added that "there's the problem, but then the innovation must stem from some secret knowledge, some insight, and some different way of looking at it."

Alan Heeger added that the depth of the knowledge should be such that "you get to a point where you have almost an intuition about what is right and what is wrong. If something is not right, you can smell it. After you have that core of knowledge and experience then you can branch out and learn other techniques, learn other experiments." He said that the right plan in educating is to "have a student start out on a very focused area, but before getting his or her degree try to work on something else."

Beyond in-depth knowledge in their field, innovators must know their capabilities and limitations. In the absence of such self-awareness, the innovator risks not being able to choose the most promising directions. Rodney Mullen values such self-efficacy and fears that, in its absence, the innovator risks not being able to choose the most promising directions: "if I am looking for the most innovative guy that has a future, [I would] ask 'Does he understand the skills he has, his weaknesses?' Choosing what not to do is unbelievably important, but by its nature is overlooked as a skill set."

### Ability to Identify Good Problems/Ideas

The interviewees cited the importance of the ability to identify a good problem. But they acknowledged that identifying a good problem is not a straightforward process. In the words of David Morse, "There is an art to innovation—knowing how to recognize things that have a chance of becoming a commercial success and what it takes to achieve that (practical) success." Robert Langer concurred: "I'm not sure that there's a single answer to that [how to identify good problems/ideas], and I don't know that there's a simple way to say that a certain idea is absolutely a good idea. It's kind of like beauty—a good idea is just like 'beauty is in the eye of the beholder.'"

Even as they acknowledged that identifying and defining problems is not an exact science, interviewees provided important guidelines for doing so:

- Spend a considerable amount of time coming up with, thinking about, and defining the problem.
- Follow your instinct/intuition.
- Choose problems based on their impact on humanity and identify where there is a need.
- Identify actionable problems—those that are practical and have solutions that can be executed.
- Target areas where there is less activity.
- Gather input from those the innovation is meant to help.
- Investigate failure and ask yourself, "Is there a path that will lead to success?"
- Identify interesting problems, ones that you feel passionate about.
- Know when to quit or change direction.

### Ability to Work at the Interfaces of Disciplines

Innovators' ability to "connect the dots" across disciplines was repeatedly cited by both the interviewees and the workshop participants, especially as innovations seem to happen at the interfaces of disciplines. Breakout session discussants pointed out that bringing a new skill set to a field can yield a different perspective.

According to David Morse, "[technological] innovation is the ability to recognize the link between some sciences to fill a function of some sort." It follows, then, that "innovators are much more cross-disciplinary than just deeply solid technically in one area," said Anoop Gupta.

> Innovators are people who are real misfits in their field, because they can see across borders, they can see across borders of discipline, geography, all of that. They're the ones who can make those disparate connections between, say, DNA and a hard drive, and say "Let me make a DNA hard drive."
>
> – *Nina Tandon*

According to Michael Frenkel, interdisciplinary teams—"people with broad and diverse areas of expertise and variety of skills working together"—are one of the main reasons the National Institute of Standards and Technology (NIST) has been able to solve complex problems.

Working in interdisciplinary teams not only allows for the exchange of knowledge and development of ideas, it also, implicitly, reduces risk. As Kalyan Handique put it, "If you work in an interdisciplinary team, you have more chance that you will come up with something valuable because there are checks and balances, you cover each other's bases, and you are trained to do something that's not just in one area of expertise."

Alyssa Panitch said that she is most innovative when she is on the fringes of what she knows and what she does not know well, and that she is less constrained by the "dogma of the disciplines" when she is operating in this space. She calls herself a "jack of all trades" and said, "I always argue that I know just enough chemistry and know just enough biology to be dangerous, and I think that that's true."

Frans Johansson considered a different angle, positing that work in a "promising" intersection may not yield successful results because it is "reactive"—someone has already identified the area as promising. The real challenge, he said, is in predicting "what the new powerful intersection is":

> I believe you end up in trouble when you try to figure out where the most fruitful intersections are at the moment. Let's say that you are looking at virtual reality technology on one hand and medical school on the other hand, and working on long-distance surgery seems fruitful. But people are already doing that, so what type of information are you using to figure out what a fruitful intersection would be? By definition it almost has to be based on what is already known to be a fruitful intersection. That does not mean that there aren't opportunities there, but you are still basing it on an experience that people are already having. So it could be fruitful, but the likelihood of you, in this instance, truly breaking new ground drops because others are already exploring these intersections.

> The more interesting intersections, in my experience, are those that are unexpected.
>
> – *Frans Johansson*

Interdisciplinary work is so important that Alan Heeger wants to be remembered as an interdisciplinary scientist: "I really think that I have great influence on modern science in that way [as an interdisciplinary scientist]. . . . These days my students come to me with data that they obtained through interactions with colleagues that I didn't even know were going on. They often publish with those colleagues, sometimes with me, sometimes without. So we are known here [at University of California, Santa Barbara] for our interdisciplinary approach to science. I'll take some credit for that."

## Ability to Sell an Idea

The ability to communicate one's ideas in a clear and inspiring way is increasingly important in the growing global information economy, and is crucial for innovators, who are often engaged in team activity. The ability to sell an idea is tightly linked to both the ability to secure funding for research or development of the idea and, as applicable, the transition from idea to implementation. In the words of Mark Randall, "if you can't recruit great people to your cause, you're probably not going to succeed as an innovator."

> Most successful innovators that I know are very good at explaining their ideas. There may be some people that are really good at coming up with ideas but really bad at explaining them, but those people usually don't get very far. Because . . . for an innovation to be successful, you'll need more people to work on it with you; you've got to convince them, and it's very hard to convince if you can't explain your idea. . . . So I think it is critical to have the ability to be able to at least explain what your idea is and also that it is a good idea.
>
> *– Luis von Ahn*

Bob Metcalfe agreed that, in contrast to the process of inventing, innovation "involves more people, involves selling your ideas, and the kind of selling that is mostly listening!" Along these lines, being aware of others' perspectives was commonly cited across the interviews.

Finally, the ability to convey the significance of one's work to different audiences is crucial. In Karen Kerr's view, "[It's important to teach students] to communicate an idea that's highly technical to a group that isn't technical."

### From the Workshop: Additional Skills and Attributes

Workshop participants were encouraged to discuss the findings during the first breakout session and suggest other skills and attributes.

Several participants stressed the importance of the *ability to handle uncertainty*, which is closely related to the ability to take risks described earlier and the experience of finding and solving open problems described in the next section. The participants explained that innovators must be prepared to do everything right and yet remain stymied in their efforts. Conversely, it was posited that an inability to tolerate uncertainty could motivate innovation, as the drive to seek a solution.

Another trait that recurred in the discussion was *persistence*. Also cast as "grit," "street smarts," "bull-headedness," and "dogged determination," this characteristic was associated with the abilities to focus on finding a solution to a problem and to move beyond failure by learning from it.

In addition to persistence, innovators need the *courage* to pursue an idea no matter what others think, as well as motivation (whether inner or outer directed), faith in their efforts, and the confidence to overcome naysayers. Both persistence and courage are closely related to passion and the ability to take risks and manage failure.

*Flexibility* was mentioned as a necessary complement to persistence—the ability and willingness to change course during a problem-solving process. Effective innovators are those who demonstrate agility and adaptability to change course and even adjust "on the fly" when needed. This "paradox" between persistence and flexibility mimics the one between passion and reason as found by the study.

Participants also discussed the capacity to receive and deal with criticism; the ability to decompose a large problem into smaller, more manageable chunks whose solution can lead to bigger results; competitiveness, the desire to be the first to find a solution; self-education, an interest in finding answers for oneself; and pie-in-the-sky imagination.

## EXPERIENCES

The interviewed innovators come from a variety of professions and fields—from music to chemistry, skateboarding to communications. While each career path or field of interest may have specific criteria for defining success, the conversations revealed that the road to success was often similarly paved across disciplines. The innovators cited the following experiences as contributing to their innovative abilities:

- interdisciplinary collaborations,
- industrial experience,
- identification and solution of open problems,
- mentorship,
- role models, and
- upbringing that nurtures innovation.

### Interdisciplinary Collaborations

Experience working in interdisciplinary teams is crucial, because, as Kalyan Handique said, "that's what happens when you go to industry, you are trying to create a product that has a lot of elements." He added that the most valuable aspect of his doctoral education was "the interdisciplinary environment," and that without it he probably would "have not gained much and would have been of less value to industry."

> [Interdisciplinary collaboration] helps us understand cultures of how biologists operate different from chemists, how engineers view the world differently, how medical doctors work, and so on. That's really valuable: understanding the significance and having some appreciation. It is also healthy as it can help you see and feel that you're contributing to something bigger.
>
> *– Ryan Bailey*

Workshop discussants noted that the members of an interdisciplinary team can expand the abilities of a single innovator by each contributing the skills and knowledge needed for a project.

Collaborative experiences also play a role in self-development. Maria Scileppi reported that "one insight was that I was meeting all of these people and connecting with them, but really I was getting to know myself, and so, it's counterintuitive, but to know others is to know yourself, and that's one of the reasons why collaboration is so valuable."

Several innovators observed that informal cross-disciplinary experiences may be undervalued. David Agus put it this way: "People from different areas get together, and we just sit and talk about a problem. I don't know in advance what the problem's even going to be, but it's those discussions that actually make all of us better, and we'll bring in a scientist from here and there and just sit down and talk and have those conversations, but we've really lost the ability in most science today to have the time to have those discussions."

## Industrial Experience

Industrial experience can be particularly beneficial for students, providing, for example, an opportunity to develop critical understanding and to identify and work on real problems. George Whitesides said that the single thing he would tell someone who aspires to be an innovator is "you should go off and somehow work with someone who is actively an entrepreneur, who is running [an innovative] company, for a couple of years, even if you have to pay for it yourself."

> Industry experience adds value for everybody. I think it's a wonderful experience to get into an industrial lab and have an internship experience or in some way get broadened. Even if the person's whole ambition is to be academic forever, it doesn't hurt, and it's not a very big time investment in terms of their overall time in college. I see tremendous learning from interns that we get here [at Corning] every summer.
>
> *– David Morse*

Some workshop participants argued for practical experience rather than specifically industrial experience, noting that any real-world context can add to the excitement of research and innovation. During the interviews, John Rogers reflected on his doctoral education, and felt "being able to do at least some fraction of your research that has an outcome that people care about, beyond your field of specialty, was an exciting thing."

Rakesh Agrawal acknowledged the value of industry experiences to his own success: "Industry experience was beneficial to me because it forced me to learn who I am! When I worked there, the very first year, I quickly realized my capabilities, which I don't think I would necessarily have been able to realize in an academic environment." Yet, he added, "involving industry in education is good, but really not as important as people often think, because you have to teach students self-learning and if they have it, then they will learn very quickly; it doesn't matter what situation they go into."

Ashifi Gogo conveyed the need for coordination between universities and industry on the nature of work assigned to students: "Industry's involvement in a measured way could be useful. The concern I have is industry may come with a very refined problem that they're seeking a solution to, and mapping that to a specific base of students who may or may not even want to work on that problem could be challenging."

### Identification and Solution of Open Problems

The experience of finding and solving open problems calls on students to define (and redefine) a problem and explore it from different angles. But this experience is not typically part of students' education.

> Schools pose a problem to which you know there is an answer, and the very fact that you know there is an answer changes the way you think about the problem. If you have a problem to which there is no known answer, you actually need to address that problem in a very different way. That's lacking in the educational system.
>
> – *Stuart Parkin*

To enable students to gain this experience, Robert Fischell described the following approach:

> Break up the class into groups of people to work together as a team, and at the beginning of every week, each team would try to find a problem that there is in the world in some field—in energy, in health care, in computers, or something—and then have each of them be a team saying, "Okay, we found something that doesn't work. It doesn't work well. Now let's work on how we can make something that's better than that. Let's think through all the variations, combinations that could make that situation better," and then that is how a noninnovator could work deliberately on making a new innovation.

Several universities provide extensive opportunities for undergraduates, even as freshmen and sophomores, to conduct research and gain experience looking at open problems and working in teams. The value of this exposure was confirmed by Holden Thorp: "I think one absolutely critical thing [for me] was doing undergraduate research. . . . I just think that's an incredibly important thing because there are all these kids who don't really know what research is and don't have any way of finding out about that."

John Rogers similarly stressed the importance of opportunities for undergraduates to conduct research: "In our lab at the University of Illinois at Urbana-Champaign, we have a super heavy engagement at the undergraduate level. We take anybody who's interested. . . . My thought is, Let them get into the lab, in a way that avoids making it so constraining or so challenging that they're going to shy away from it for that reason. Just bring them in and give them a chance. What we do around undergraduate research experiences is different from anything that I've seen before, certainly in the scale, probably the style as well."

### Mentorship

The value of mentorship was cited by all the interviewed innovators, and workshop participants concurred that mentorship provided at the right time can make the difference in perseverance and success. Doug Hart said that "Being mentored by really outstanding people was hugely valuable to me. I think it's one thing to be creative, but to be innovative you have to make that leap into something else, and that leap, I think, is something that needs to be taught, in a way [through mentorship]."

Along with having good mentors, the innovators and workshop discussants cited the importance of being a good mentor. "Find good mentors and be a good mentor yourself" is how Rakesh Agrawal would advise anyone who wants to nurture innovation. Don Sadoway said, "As a good mentor, I wanted to lose snap judgment and condemnatory behavior. It's really delicate, how to mentor people in a way that holds them to high standards but at the same time doesn't strip them of self-esteem, doesn't embarrass them." It is probably not surprising that a good mentor, according to Richard Tapia, would be one whose mentee can say to him, "You don't make me feel inferior. You make me feel that I belong. You make me feel like I can succeed. . . ."

Tim Cook mentioned the value of having Steve Jobs as a mentor, emphasizing the importance of observing how Jobs thought rather than just focusing on what he did: "I had an incredible mentor with Steve, and working with him and watching him and seeing how his mind worked was incredible, . . . a lifetime worth of experiences."

Mentoring, according to Varun Soni, is paramount because any one model of teaching innovation cannot apply to every student:

> I think everyone can think innovatively, but some students are more innovative and creative than others. So I think one of the aspects of innovation, from a university perspective, is to be able to identify who has these kinds of innovative orientations and how to best support that. And that, I don't think, can be scalable. I don't think we can cut and paste an innovation model that makes sense for all of our innovative students. That, I think, is where mentoring becomes paramount, where individual advisors would be able to identify certain aspects of some students' work and support those aspects in a different way than that professor might support another innovative idea from a different student, because students are coming at these from different contexts.

### Role Models

Whereas mentors have a direct role in nurturing the innovative abilities of students, role models serve as a source of inspiration and example of success. Mentors can also be role models, but this is not always the case. John Hennessy clarified that "role models clearly are inspiring! You can say, 'Here's the office that Larry Page and Sergey Brin had when they started Google,' and people find that inspiring and think that they could do that."

Robert Metcalfe colorfully illustrated the point:

> You get two things from role models. One is you discover they're just like you, or worse! Then you really know—"God, if this idiot could invent something, I'm sure I

can!" And then role models show you the steps, like you build something, you write a paper, you study the literature to be sure you're not duplicating effort, you stand on the shoulders of giants, you look at things from different angles, you combine expertise in a multidisciplinary way, blah, blah, blah, . . . and if you just do that every day, then you start innovating.

To expose students to role models, a number of innovators recommended teaching "history" in the STEM curriculum. According to Michael Frenkel, "You could design a course which you would call 'The History of Innovation in Engineering,' and during this course illustrate successes in developing new technology and making them broad-based innovations. And in doing that you could also illustrate the examples of real lives of the people who have been involved, because very often knowledge is being communicated without any connection to the very people who developed it, and that makes it very inhuman. I believe if people have examples of success, they will be in a better position to be successful themselves."

On the other hand, talk of role models usually focuses on their successes, rarely their failures. But telling the latter can be equally instructive and even inspiring. As Bernard Meyerson put it, "The hardest thing is to kill a program, and the ones we failed to kill are the ones that almost killed us, and so it is extremely valuable to tell people those failure stories. There's a lot of lessons learned."

> [When I lecture at universities] I start out by saying "I'm not going to tell you how I succeeded, because frankly I don't know. I can pretend that I know, but I'm just retrofitting success backward onto things; most books written about successful companies are just retrofitting based on what happened. But what I can do is tell you how to fail better, because that I know a lot about." And then I just talk all about my failures, and a lot of people are like "Wow, we finished 90 minutes with Mark, and he never talked about, you know, these big innovations." You don't learn much from those! Those are the random things that happen because you tried so much, and you were able to try so much because you were good at failing.
>
> *– Mark Randall*

### Upbringing That Nurtures Innovation

Many of the interviewees described their lives at home as influential to their innovative capabilities. Sometimes the influence was related to one or both of their parents' occupations. Amy Salzhauer, for example, attended board meetings with her father as a child, which exposed her to corporate governance. Doug Hart felt that having an artist mother and an engineer father helped him become inventive, which in turn is important to be innovative.

Participants also cited the influence of their parents' values, some giving weight to the value of education. Dwayne Spradlin recalled his parents finding ways to get his books and lab equipment as a child, despite being relatively poor.

Frans Johansson said his experience growing up in an interracial and multiethnic family contributed to his openness to diversity, despite the fact that the town in Sweden in which he was raised was not very socially diverse.

Spending some of his childhood in the projects of the "worst parts of Brooklyn," Carmichael Roberts grew up in an environment with few resources. From this experience he learned to be resourceful to create with whatever limited resources were available—and defied the "statistic that there's no way, if they took a snapshot of that child [me] at that time, I'd be doing what I'm doing now."

Supportive structures identified as conducive to innovation in childhood are those that allow children to take risks, follow their passion, and think broadly. Agreeing that "you do need to be creative in order to innovate," Mary Ann Meador was not sure whether one can be taught to be creative or innovative, but she *is* sure that "you don't want to do things that will curb their creativity."

Several innovators described two key characteristics of their childhood activities: having enough time to think and observe, and being able to tinker with things. Successful innovators seem to have had a childhood that was "slow-paced" with lots of time to think and observe.

> I'd look at the clouds and think, and I had a lot of summers just not doing much of anything, just sitting around. I read a lot of books once I got interested in reading, but I did not do a lot of experiments, a lot of science or anything like that . . . and I never had a lot of homework. I think it's a leisurely pace. . . . We hope that people don't have to come from one-room schoolhouses, but I'm wondering how well people are going to think when they're multitasking all the time today.
>
> *– Robert Dennard*

Unstructured time compels children to do something different, something to entertain themselves using the "tools" at their disposal. Doug Hart said, "If you've got unstructured time and if you have these toys at your disposal, you go down and you start putting pieces together and you say 'Gee'—just out of boredom—'what can I build?' . . . Boredom can be a wonderful thing!"

There is a concern that today's kids may be overprogrammed. "You need to have hours to take something apart and put it back together or create new things," said Holden Thorp, and "kids don't have that kind of time in the same way anymore." He said: "My mom ran the community theater in my home town, and there were a lot of things there to tinker with—set pieces that rolled around and the lighting board and sound equipment—so I spent a lot of time early on learning about and fixing all of those kinds of things, and I got interested in music. I was constantly inventing new ways to do multitrack recording on equipment that wasn't really designed for that."

Bob Metcalfe advised that when kids are allowed to tinker with things, they should not be punished for their creations (or their failure) nor blamed for it. He recollected: "The wooden raft I built for our summer house broke apart, and my father declared it a failure. He overruled my desire to repair it because he saw that it was a lost cause. [But] there was no punishment. . . . It's just something that didn't work out, and so he cut it loose. It was his decision to abandon the project, and I went along, but I have long remembered that I wasn't blamed for it."

### From the Workshop: Additional Experiences

Asked during the workshop's first breakout session to discuss the list generated from the innovator interviews and identify whether anything was missing, participants reiterated the importance of *failure* and, ideally, the experience of trial, error, and failure followed by success. *Playfulness* was also proposed, together with tinkering and experimenting. These were echoed during the interviews in the context of environments that encourage risk taking and provide freedom to tinker as discussed in the next section.

## ENVIRONMENTS

Environments, both physical and social, are a significant factor in the formation of innovators who have the skills and experiences needed for success. In 1916 John Dewey wrote, "We never educate directly, but indirectly by means of the environment. Whether we permit chance environments to do the work, or whether we design environments for the purpose, makes a great difference."[1]

"Chance" environments could also include family and country or culture of origin. US culture differs from others in important ways, according to several workshop participants; irreverence, for example, distinguishes US from Asian culture. Indeed, some felt that the American experience as a whole supports innovation. In this context, it is important to note that environments can change by, for example, a move from one country to another. Another participant compared the life of an immigrant to a startup: as an outsider, there seems to be less to lose, the unknown is familiar, taking a chance doesn't seem as risky.

Interviewees and workshop participants observed that although children enter school full of curiosity, creativity, and other promising skills, the educational environments seem not to encourage but actually discourage the development and enhancement of skills. Academic institutions should *design* an environment that provides experiences to the students to develop or enhance skills needed to become successful innovators. Guidance, independence, accessibility, flexibility, encouragement, socialization—these are elements of an environment that help students to be innovative.

George Whitesides observed that the best innovative environment takes the form of a *social enterprise* that helps people do what they want to do. In fact, he recognized

[1] Dewey, John. 1916. *Democracy and Education: An Introduction to the Philosophy of Education.* Macmillan.

it as more valuable than any particular research activity of his accomplished research and innovation career:

> People ask me, "What's the most interesting thing that you've done in your research?" and the answer that I give in my old age is actually a little surprising, which is not so much one area of research relative to another area, but to understand that a research group runs best when you think about it as a social enterprise. By that what I mean is my job is to help very smart people—and most who come to graduate school, or to postdoc, are an amazingly smart group of people. They've been screened by the most imaginative systems in the world and they ended up here. So my job is not to recognize and teach [doing research or innovation]—they know what they want to do, but they may not be able to articulate it. The job of the environment is to make it possible for people to do what they want to do . . . and unless you think about it as a social enterprise, you don't get the benefit of the skills and the diversity of skills that are present.

Environment is more than a class or curriculum; it implies an immersive experience, which is appropriate to the cultivation of an innovative mindset just as ethical thinking and practice cannot properly be contained or taught in a single course.

> There are ethics courses, but ethics has to be a part of someone and therefore a part of everything that they do, not something that they do for an hour or whatever. I think innovation is more like that and you want to think more about innovation as an underlying skill and try to sprinkle it through the whole of the curriculum, and really try to get at it from the cultural and the environment point of view, not from some single class that you were teaching. It's not like teaching economics or calculus or physics; it's not like that.
>
> *–Tim Cook*

Probably the most significant challenge in putting such environments in place was captured by Richard Miller, who asked, "How can you engineer a change so that an existing organization will embrace it?"

The innovators' thoughts and recollections about environment yielded the most detailed understanding of the types and characteristics of this influence on their lives. Environments that encourage innovation should

- explicitly encourage innovation,
- have physical spaces for free/open/informal discussions,
- facilitate interdisciplinary collaboration,
- encourage following one's passion,
- place a strong emphasis on the value of education, and
- provide freedom to tinker.

### Explicitly Encourage Innovation

John Hennessy described the campus of Stanford University, which is known for its successful innovators, and its effect on students: "Students come in, and it's fascinating to watch when we do our tours around campus. The tour goes down to the engineering quadrangle, and they say 'Well, that's the Jen-Hsun Huang engineering building. He's the guy that started NVidia. That's the Jerry and Akiko Yang building. He's the guy that started Yahoo!' So they walk around and they're in this setting where people who have changed the world once lived, and it's inspiring to young people, they think 'I can do that too.' That's exactly what they think."

Amy Salzhauer, who graduated from the Massachusetts Institute of Technology (MIT), said she could "*feel* that MIT really values innovation," in part because innovation was talked about "All the time! *All* the time!"

Government agencies, too, have environments that foster innovation, as Michael Frenkel explained: "NIST has an institutional culture that has focused on promoting excellence and innovation, and that also creates particular ethical guidelines, particularly for young people when they come, for the art of doing science and engineering right. This seems to be something NIST has known for years—encouraging this type of culture."

Brian Hinman emphasized the value of such an environment. According to him, you could "take a person who otherwise could be quite innovative and put him into an environment that does not reward and encourage innovation. [That person] could end up not developing to the full potential."

One of the ways of encouraging innovation, beyond verbalizing it, is by rewarding innovative thinking.

> When you're pursuing truly new, never-been-done-before things, you cannot give up if you encounter a failure along the way. There will always be points of failure along the way. At those points, the organizational participants and their leaders must have steely nerves. We must reward people who take a big swing, even if there's an initial failure.
>
> *– Regina Dugan*

### Have Physical Spaces for Free/Open/Informal Discussions

The value of physical spaces for informal discussions in fostering innovation was repeatedly mentioned by the innovators, who felt that the best innovative ideas seem to occur through informal discussions, sometimes over coffee. David Morse elaborated: "Facility ergonomics are important to maximize the cross-pollination of the inventive capacity of an organization: offices, labs, common sharing areas, IT-enabled conference rooms, large gathering areas for open technical reviews and poster sessions."

The key, according to Anoop Gupta, is in ensuring informality: "I think informality helps. It could be in the office sitting across from a colleague, it could be over coffee, lunch, on a paper napkin. I think informality and an open mind are conducive rather than 'forced' innovation. 'I shall innovate now!' It doesn't happen that way."

> There have to be areas for people, without planning, to meet. For us it's our lobbies, which essentially are like huge coffee shops. There's a café and it's great to eat there, people don't run out for lunch. Then there is the quad area where people sit outside. It's in areas like that where it's a natural, unplanned, serendipitous sort of informal collaboration. And then, if you went into some of our most creative areas, you would find that people sit at a table and have lunch together and sit across from each other on benches, and it's like your family used to sit at the dining room table. That's how they discuss and decide things. So I do think that office space, environment, culture—all of these things play heavily in this.
>
> *–Tim Cook*

In the planning and creation of office spaces, Frans Johansson noted that "One has to be mindful that people have different styles. At the same time, you have to encourage dramatic interaction, long interaction. It's simply not acceptable for somebody to say, 'I'm going to do all this all by myself.'"

Carmichael Roberts suggested that "what we should visualize is not a static office space, more of a 'How do I immerse myself in different environments?' to help who's there to get the practical stuff done, but also to stimulate my mind to do some other things."

Clearly, certain decisions about the work environment can be more (or less) conducive to successful innovation. From the days of the single-room office with a door to the more recent cubicles and rooms with bean bags, Robert Metcalfe said he's seen it all in his career and believes that current open office designs and workspaces support the exchange of ideas: "We've reached the point where the cubicle is passé, and you just stack tables upon tables and fill them up with monitors, and people jack in and put headphones on, and they're like cattle in a big open room, and that's what Google and Facebook and everybody looks like. I'm convinced that it works—that is, the idea of putting people in proximity and dropping the walls has a generally positive effect, most to motivation and morale, but also to idea exchange."

Whatever the structure or organization, Nina Tandon cited four elements to keep in mind in designing physical space:

- *proximity* to ensure that multidisciplinary people are close to each other;
- *interdependence* because unless people are interdependent they won't collaborate;
- *untidiness*—an open area for freeform discussions and experimentations; and
- *privacy*, because most innovative thinking happens during private downtime.

Echoing these points, Varun Soni called for expanding the focus beyond the classroom, because "for students, the most transformative moments in their life happen within the university context but outside the classroom. They happen in study abroad experiences, they happen in conversations in your dorm rooms, they happen in student religious life or community service or undergraduate student government or fraternities and sororities or recreational sports." He went on to explain the value of the non-physical, inner life—the "virtual space," which is increasingly important in the digital age, and the "spiritual space."

> The space inside the person is the contemplative space . . . where the best innovative thinking happens. It doesn't happen in the office but at home, on the treadmill. . . . It happens when I'm not thinking about work, honestly. . . . It's really critically important for the health of the organization for people not to think about the organization, to take time away, to safely guard their vacation space, to get out of their own head every once in a while.
>
> —*Varun Soni*

### Facilitate Interdisciplinary Collaboration

Collaboration was mentioned by many innovators, together with the observation that innovation happens at the interfaces of disciplines. They identified the following characteristics of environments that facilitate collaboration:

- *Intellectual freedom.* Michael Frenkel stated that "Intellectual freedom is an extremely important component for success in science and engineering, and intellectual freedom implies the free exchange of information and collaborative efforts, but again culture itself plays a significant role."
- *Interdependence.* According to Nina Tandon, "There's a role for interdependence of people [from different disciplines]. When people are interdependent on each other, it creates collaboration."
- *Explicit encouragement and training.* Yoram Bresler observed, "I think academic culture in some cases stifles collaboration, and in my case it wasn't that it stifled it but it did not encourage it. I needed to be retrained opposite to my own inclination, because some people are inclined to be collaborators just naturally, and they'll do it. Others need to be encouraged and trained."
- *Provision of tools for collaboration.* Spaces should be designed knowing that collaboration depends on the exchange of ideas. Karen Kerr described one approach: "I used to work with Krisztina Holly at the University of Southern California, and one of the things that she did in outfitting the space at the Stevens Center was she had a lot of the walls painted . . . not the chalk board, but writeable walls, so you could just write all over them in huge swaths of space—I had a whole wall in my office that I could write on as a white board. That's very useful, because then people can draw and they can think together."

> I believe innovation is a team sport. It's not something that's done in isolation. If you look at Bell Labs, if you look at 3M, if you look at Google, if you look at Pixar, all of the companies that are really innovative, it's a team sport, and the team's made up of intentionally diverse backgrounds. You don't have a department with mechanical engineers in it. At Pixar [for example], you have an artist, a cinematographer, a computer scientist, and a mechanical engineer. That's your team.
>
> *– Richard K. Miller*

One approach suggested by more than one innovator was theme-based rather than skills-based academic departments to encourage interdisciplinary education. As John Hennessy put it: "Nearly all the buildings we've built in science and engineering side of the campus in the last 10 years, none of them belong to a single department. They all mix disciplines, they mix fields. They're thematic, like there's an environment and energy building, there's a nanosystems building, nanotechnology building. We've tried to distinctly mix things up, because place is important. And the other key thing I think we've done that's been successful is for new activities where we're trying to inspire and encourage cross-disciplinary work, we've actually had a venture fund that will fund faculty research projects, . . . and the key rule is that it has to include faculty from at least two different departments who've never collaborated before."

An open-door policy, suggested at the workshop, would allow students from all departments to use the equipment and lab space of any other department and thus foster interaction among students from different disciplines with different skill sets.

Ivan Seidenberg said students should be required to learn multiple disciplines and that educational environments should ensure that. In his words, "I'd like a graduating student to be an expert in, say, accounting and learn all the disciplines needed to do all of the high-quality research and the use of technology and all that kind of thing, and I'd also like to see the person in marketing do that."

### Encourage Following One's Passion

As mentioned among the skills and attributes, every innovator is passionate. Is it possible to create environments that help people to be passionate? In John Rogers' opinion, "people are most successful if they're passionate about something, and that's a very personal type of thing. You can't engineer that, you can't teach that." Even so, it is helpful to recognize what might stir a person's passion, because "it is also a good proxy for when they're going to be at their innovative best," according to Dwayne Spradlin. This knowledge may help educators understand how to evoke the passion of their students.

Innovators were clear that passion is not usually about money; it is present when they're working on real-world problems that they believe matter. In the context of education, Beth Noveck explained the importance of asking students to identify what they deeply care about: "We're learning with students that, building off their interests and the things they care about, to then learn skills using that subject matter has a much more powerful effect than trying to force them to be interested in something else."

### Place a Strong Emphasis on the Value of Education

Most innovators felt that they grew up in environments that stressed the value of education; for some it was their family, for others their school. For Alan Heeger, his path toward being a successful innovator started with his mother: "I give the credit to my mother, who insisted, right from my earliest memories, that I should go to university. She didn't tell me to be a scientist, but she emphasized that education was important. So that's how I got started."

> What we can educate students on is that it is critically important to be very well prepared on whatever the subject is for which they are seeking to create an innovation or invention. They need to do a lot of background homework, understand the context, and understand what's happening in the world with respect to that particular area, so that the mind is well prepared when a significant event occurs.
>
> – *Uma Chowdhry*

The innovators recognized that, in addition to all the skills and experiences described above, students must be prepared in a "useful" field to succeed in the global economy. As Ivan Seidenberg explained, "Schools, universities need to prepare kids. If we don't make sure they have a discipline that's worthy of making a contribution, they're going to get outflanked by all the kids coming out of China and Korea and all these other places. So going to the local community college and majoring in whatever, music, isn't going to help you unless you really want to be in music, then that's okay, but if you're just doing music to get through school, then you'd better go back and learn something that's going to be useful to you. I sound like the typical cranky old guy, but I think kids need to hear these things!"

### Provide Freedom to Tinker

Innovators often mentioned the value of environments that allowed them to tinker. Beth Noveck feels that an environment that helps people realize and exercise their "maker muscle" is incredibly important:

> I think it is this idea of making and building and doing, in whatever domain interests one—it can be cooking, it could be coding—and exercising that muscle of human creativity, realizing one's own ability and power as a maker and as a doer, that is incredibly important to nurturing the skill set that it takes to be an innovator. It's really about initially having the confidence to realize that you have the power to make things and to change your own conditions around you. And that can come from . . . exercising this sort of "maker muscle."

Innovators and workshop participants agreed that the freedom to tinker implicitly includes tolerance of failure, with the understanding that failure is part of an iterative process of trying, learning, and adjusting. As Sundaresh (Sundu) Brahmasandra put it, "There should be that tolerance to failure. I think the biggest thing is people are afraid to fail, and any environment that can teach that failure is not really a failure, failure is just an obstacle in some sense, is going to be very crucial. . . . We need to advocate that a failure should not usually be pinned on a person but on a process, or is a part of the process."

> In my view, we should celebrate the passion to build . . . the impatience to build . . . and encourage people to instantiate their ideas. I love doer-dreamers: those who have a vision and then try to make it so. This is one reason why the maker movement is important. It's a return in the country to making things. We need to encourage people to be creators.
>
> *– Regina Dugan*

### From the Workshop: Additional Environmental Features

Some breakout group members felt the need for freedom from *constraints* such as funding and time, whereas others pointed to the utility of learning how to convert a constraint into a resource. On a national scale, some participants felt that reducing *bureaucracy* in the United States would improve its environment, which is already considered to be supportive of innovation. Workshop participants also made the point that adverse circumstances in one's youth (e.g., challenges associated with low socioeconomic status) need not determine one's success as an innovator. In fact, adverse environments foster innovation; this was also mentioned by several interviewees when discussing reasons that lead to an innovative idea.

# 5

# Key Questions, Takeaways, and Next Steps: Workshop Discussions

Breakout session I at the workshop presented the participants with key questions posed by the steering committee to advance discussion beyond the findings of the study. These breakout groups were a mix of participants across different sectors. For guided discussions in breakout sessions II and III, participants reconvened in four stakeholder groups—large business, academia, small business, and K–12 education—to synthesize the information from both the interviews and the earlier breakout group discussions in order to determine takeaways and next steps.[1] Each group was asked to distill observations from the second breakout group discussion, to consider what else they would like to learn from the interview analysis (appendix D), and to identify action items as well as roadblocks, points of leverage, and other stakeholders to be involved. These accounts of the group discussions convey the views of individuals, not the consensus of any group or of the project committee.

## DISCUSSIONS OF KEY QUESTIONS IN MIXED GROUPS

### Question 1

*Are innovators different from entrepreneurs and intrapreneurs? How best to build natural bridges between innovation and entre-/intrapreneurship?*

The group members discussed the definitions of *innovation* (successful new implementation) and *entrepreneurship* (value creation), as well as *science* (discovery), *engineering* (creation), and *invention* (realization of an idea), and distinguished the attributes

[1] The groups also included participants from professional societies and federal agencies as well as people active in the arts and media.

required for entrepreneurs (people/communication skills to create value) and inventors (more internally motivated/problem solvers). They then identified one attribute that is crucial and needed in every innovator: the drive to want to solve a problem. And since innovation is driven by the interplay of self-motivation, environment, and role models/mentors, the nuances of intrinsic motivation need to be determined. One way to help students discern and develop this trait is to ask, "Whose life do you want to change?"

An important corollary is that innovators should be lifelong learners and this should be fostered by the educational environment. It is thus important to teach students *how* to learn. They also need to have experiences working and interacting with a wide range of disciplines, which must include art and design—STEM should be changed to STEAM, where the "A" stands for arts. The focus must not be only on science-based innovation; innovators are needed in every sector. To that end, the goal should be to create and nurture an inner passion about ideas in general.

### Question II

*How do we transition our learnings associated with enhancing individual innovation capacity to group/team innovation capacity? How can this be further extended into open innovation environments?*

Participants observed that every child is born an innovator and this gets de-programmed before s/he reaches university. Students need opportunities to develop innovation skills before they get to college, and they need to be encouraged to put the same energy into science, technology, engineering, or mathematics as they put into athletics. They need basic skills and tools and need to know how to apply them.

In addition, there was concern that children are being raised to care about how much they are liked, whereas a great innovator has to want an idea to be as great as it can be independent of popularity or risk of failure. Experience with failure is important as it helps build the courage to keep going, but rewards for failure are not aligned. Furthermore, an environment that is tolerant of failure does not have to lack competition. The best entrepreneurs are often intensely competitive. So it is a mistake to assume that stripping measures such as grades and scores out of the educational setting will be a benefit—for some people these measures help motivate them and show progress. There should be a mix, and different types of motivation and achievement should be accounted for when devising measures of student progress.

Students need opportunities to cultivate both self-direction and the courage to pursue an idea no matter what others think of them. They should also learn risk management, an important skill for good decision making and critical problem solving. The best innovators know how to manage risk. Risk management—and the benefits of taking risks—should be taught before college by teaching critical problem solving at an early age.

Unfortunately, students learn to avoid risks that threaten their grades. Educators must work to avoid this effect when students are young. Universities should rely less on SATs because the emphasis on grades and test scores depresses innovation. They should also change metrics for admission from high school to include some creativity.

Looking beyond the classroom, some major companies (such as GE) are looking to hire people who have more diverse experience. For young people who perceive more social value placed on entertainment, a career in science or academia may not be appealing. For these reasons high school students need to be exposed to the real world through educational opportunities outside the school day/school year, such as work in a laboratory for 4 weeks during the summer with a 2-week break, or extracurricular R&D groups for science competitions. Outside internships can also provide opportunities to solve real problems and help students learn “soft skills.”

In short, a culture change among academics is needed to facilitate this new type of educational approach and universities need to facilitate the process however possible.

## Question III

*In the academic and federal research-funding world, merit review is the Holy Grail. But merit reviews and taxpayer dollars often fund conservative ideas. How can graduate students be trained to be innovative in this environment?*

“Merit” review is really peer review, according to some of the participants; politics are involved. Merit review should take into account how teachers are evaluated: they are held accountable to the curriculum, but this can mean that in the classroom they don’t have the freedom to teach creatively. And for students who want to start new companies, the current system requires publishing. Academics should recognize the value of patents and products in addition to the value of publications, and new criteria (at NSF) should change from the five most significant publications to recognize the five most significant products.

Funding should be used to promote an innovative environment. Conservative ideas are those with little risk, which are close to delivery. Professors/researchers can combine multiple parallel projects that vary in risk/reward—some “safe,” some more innovative. Faculty should similarly be encouraged to go after diverse projects, some with specific goals and some with broader objectives. An important corollary addresses the inherently different concerns of professors and students: Professors have to be mindful of tenure track, but they should get out of the students’ way! Faculty members can worry about their own careers, but give students freedom.

Employers look for people who have worked on teams, but universities are not promoting collaboration; the university system encourages individual success so the individual can get sole credit. Universities need to put together project teams that include business, finance, product development, and engineering. They also need to link innovation and entrepreneurship if business-worthy ideas are to be generated and new jobs created.

### QUESTION IV

*What criteria do we use to seek out the best paradigm(s) for education for innovation? What new elements do we need to consider in the "educate" piece?*

Group members added their own questions: Did you foster innovation? How do you know? How do you define success—as one innovation or many? If the latter, then how many? Have you encouraged people who have not followed an innovative path to follow that path? Do you compare school/program graduates with a baseline cohort?

Criteria need to be measurable. Results or outputs should be a criterion. Tangible short- and long-term measures of success should be considered, as well as longitudinal measurements. Another idea was to ask "Are all your students having the experiences listed under 'experiences' in the survey findings?"

A participant from the large business sector explained that newer measures of success in innovation are yielded by questions such as, "Did you get to a decision point in your project team?" "Did you collectively achieve what you set out to do?" "How did you bring everybody together for innovation?" In other words, there is emphasis on the group, not the individual innovator.

One key characteristic is that innovators must learn to improvise, like musicians. Improvisation is prized in environments where innovation occurs. Similarly, it can be useful to learn from the pedagogies of the arts and humanities. For example, use the environment and culture of the art studio, where space is often shared with neighbors and works of art are commented on by colleagues who stop by or share the studio space. Cross-fertilize artists working next to biologists doing lab work; and provide opportunities for engineers to learn about the humanities and think about how this knowledge influences design. Bring creativity into places that do not normally have time to create or play or improvise, such as traditional, "classical" engineering undergraduate programs in which the courses are tightly proscribed in the first two years. These are ways to value divergent and convergent thinking.

Start by identifying what kids really care about. For example, invite students to identify a group of people they would like to help, as teachers do at Olin College. Then take them out to learn more about that group of people and construct a sociological profile of them. This process taps students' intrinsic motivation to help people and provides an opportunity to combine education and practice.

## DISCUSSIONS OF TAKEAWAYS AND NEXT STEPS IN SECTOR-SPECIFIC GROUPS

Discussions of takeaways and next steps were conducted in sector-specific groups as follows.

## Large Business

Participants in this subgroup cited the importance to innovators of science and engineering education: fundamental knowledge of how the natural world works is essential to invention and innovation, as is critical thinking. These abilities and areas of knowledge should be prioritized equally with the teaching of fundamental skills. Students should also learn how to create from scratch and be exposed to the challenge of implementation, not merely the solution of hypothetical problems. Faced with real problems to solve, students should be guided to draw on their knowledge to work on them; invention will follow from their seeing the solution.

### *Takeaways*

- This group envisioned overlapping skill sets in a Venn diagram, where no skill is more important than another: A team needs to have a full set of skills, including those of both innovation and entrepreneurship, and innovation must be created in every sector, not just science-based areas.
- While experience working in teams is important, overdependence on team members should be avoided—individual skills are also important.
- Innovators have appropriate skepticism, they ask questions that go against the grain, they ask "what if." Innovation is thus about challenging the prevailing world view and being willing to drive toward change, and students' effectiveness in challenging the status quo will depend on their ability to articulate the value of their projects. Therefore, an environment that caters to innovation should teach students to communicate well. Schools are typically not good at this.

### *Next Steps and Further Research*

- *Further research:* Conduct further interviews with people who hire and work with the innovators that were interviewed; these perspectives might be more objective (self-reporting can be misleading) and offer useful insight on what makes innovators so innovative.
- *Further research:* Some natural attributes cannot be taught so it may be more useful to think about how to avoid destroying them. Research to identify what *prevents* innovation would be helpful.
- *Further research:* Are government policy and programs key drivers of innovation since they are behind the education funding?
- *Further research:* How do the intellectual property policies of universities vary? And what is their impact on affiliated innovators?
- Create a standardized protocol for engagement and transfer of intellectual property between industry and universities. Efficient mechanisms are needed to bridge the gap that respects the needs of both.

  *Suggestion:* Start by creating a "best practices" agreement among 10 universities and 10 businesses—others may be more willing to follow once such an agreement has been developed and implemented—then modify as needed in particular cases. Universities in other countries seem to be easier to work with because the agreements are less complicated.

- Close the gap between what universities are teaching and what businesses need. Businesses must better define the talent needed in order to drive change in the education system. Create an environment of helping universities, not telling them what to do.

  *Suggestion:* Since education is slow to change—curriculum cannot be easily adjusted—and the talent needed in different businesses is diverse, it might be more effective to change the education system through "pull, not push," for example by creating challenges and having instructors teach to the challenge.

  *Suggestion:* Businesses could partner with universities to send a representative to the campus to coteach, consult, or mentor students. This approach might also help keep talent local by providing students with a direct link to employment in the community.

  *Suggestion:* Undergraduate curriculum reform may be appropriate to reflect the need for both basic skill knowledge and critical thinking/problem-solving skills. "Real world" components should be added to undergraduate curricula to help students understand the context for learning the skills.

  *Suggestion:* Challenge promotes innovation. Business-sponsored competitions on campuses create incentives for many more students to engage than might be the case in a classroom setting.

- Recent culture has taught students that failure is not acceptable/expected. An "everyone wins" approach leads students to think success is quick and easy. Create the right messages so that students have realistic views about innovation:

  — Innovation is difficult.
  — Innovation requires patience.
  — Failure is a natural part of the journey toward success.
  — Success has many definitions.

  *Suggestion:* Schools could create a more realistic environment in which students can experience small failures and learn how to be resilient through experience and debriefing. This isn't about encouraging failure but supporting the idea that it is *acceptable* to fail and recover. Success in innovation is more about give and take, limitations and challenge and less about straight risk and failure *or* success. "Do, Fail, Learn."

- Colleges and employers should embrace internships or co-ops. Innovation improves with learning cycles. Graduation/degree requirements should rely more on competency and less on attendance. Rethink the idea of a "reimbursable event" in education. Redefine what students are paying for.

*Suggestion:* This might include 6-month to 1-year internships in a program in which students would stop taking classes, go to work, and then return to classes.

- Leverage technology to foster widespread access to learning and collaborating. Emphasize the use of electronic resources (such as online gaming) so students have the opportunity to learn both the fundamentals and how to be part of a successful team. This broadens their ability to use a variety of models to be part of an innovative, diverse culture.
- Rethink/reframe the definition of innovation in the eyes of the public and stakeholders to include all systems, not just the end product. Some companies don't need "innovators" right out of college but want to foster/support those tendencies for when those employees become more experienced.

*Suggestion:* Companies can accomplish the above by fostering idea generation throughout company systems and across jobs. Caution: Not all innovation is equal; schools and companies should steer innovation toward positive impacts (without making value judgments).

## Academia

The members of this group focused on the relationship between university-level education and industry to determine whether the skills gained from higher education and those desired by employers are in alignment. To meet industry expectations, the group made suggestions to instigate a culture shift. Rather than starting over from scratch, the group recommended integrating experiences that foster innovation in existing coursework, letting larger universities lead such efforts and serve as models for smaller institutions.

The group characterized four types of innovators: a "Steve Jobs type," those who are intensely dedicated with strong communication abilities, those with salesmanship abilities, and those who thrive in a hierarchical and militaristic lead/follow paradigm. Military-type experience is useful leadership training—it teaches how to lead as well as follow for the best functioning team. One can't prepare for leadership ranks without knowing how to follow.

### *Takeaways*

- Companies do not hire teams—they hire individuals, who must be able to collaborate and succeed in a team environment.
- You can't be an innovator unless you know enough about people and what they need to create a solution that changes their lives.
- It may be useful to flip the curriculum by beginning with orientation to the field (such as the mining industry) and providing basic knowledge about it, then turning to science education.
- Ask students to frame problems, not just solve them, as part of their homework.

- Incorporate entrepreneurship in the curriculum.

  *Examples:* (1) Ask students to set up a startup company. (2) Set up an "entrepreneurs' garage," a space for interested students to network with the outside, to hold informal "fireside chats," to hear war and success stories. Involvement is not graded. The experience has proved very useful and resulted in students forming their own teams. (3) University of Maryland students built a house on the Mall in Washington, involving work with outside contractors and real experience; but, although industry loved it and extended many job offers, the university decided not to pursue the experience again because no academic credit was associated with it; future efforts were the responsibility of volunteers. (4) Olin College of Engineering expects each student to have a "Passionate Pursuit" and records it on transcripts.

- It would be ideal to integrate entrepreneurship throughout the university, but one problem is that few faculty members are innovative themselves or have startup experience and there are too few mentors. One option is to create a summer entrepreneurship program, thus cycling new people onto the faculty with this experience.
- Share best practices from successful programs, recognizing that models may not translate to all and that it takes time to change the culture of an institution; be prepared for a transitional phase.
- There are different kinds of innovators, and the relevance of certain skills over others depends on the situation at hand. Therefore, there cannot be a one-size-fits-all approach to innovation. A group of innovators with different skills can come together to form a good innovative team.
- There is concern about the skills being taught to students and their relevance to contemporary work settings. Students need knowledge and skills that are both broad and specific, but finding the balance is difficult.
- The more constraining the credentials for entering college are, the more difficult it might be to make changes in a career or academic path. Such constraints are the result of historic practices in academia, not employers' hopes.
- Traditional educational approaches can be supplemented with real-world experiences integrated in the curriculum. Employers can be brought to the classroom to discuss what is typically sought in new employees, or students can go to employers through internships and develop the soft skills needed for success.

### *Next Steps and Further Research*

- *Further research:* Incentives need to be examined—what is rewarded?
- *Further research:* Does innovation have a positive impact on diversity?
- *Further research:* What are the specific skills of innovation and entrepreneurship?
- Work toward a culture shift in academia, because it seems that educating to innovate is at odds with the way many universities operate currently. Academia should reevaluate the reasons for teaching traditional and heavily structured knowledge, which may conflict with the expectations of today's employers.

- Convince faculty of the usefulness of innovative approaches and educating to innovate. Teach with other faculty good at teaching process, or with someone from industry.
- Assessment metrics now used include number of licenses, revenues, royalties; these are the wrong ones for students. In addition, most startups fail, so the success of a startup is not the right metric. Universities and departments should decide on metrics, not the accreditation commission, which pushes universities to measure student competency, but what is the competency in question? Redefine assessment metrics so that they reflect changes in culture and student competency.[2]
- Weave innovation-related knowledge and experiences (e.g., risk taking and management, failure, real-world problems, mentors) into existing courses, because it is difficult to start new courses and programs from scratch, and because innovation should be pervasive in the academic environment.
- Require students (especially in engineering) to be exposed to innovation and entrepreneurship (e.g., learn how to start/run a business) in order to graduate.

  *Options:* (1) assign teams of students 30 days to design a city or solve some problem requiring innovation; (2) ask students to identify a group of people whose lives they want to change, as in a business plan competition, and to articulate learning outcomes. Also teach engineers to talk to customers.

- Encourage freshmen to find what inspires them and expose them to a multidisciplinary team, role models, and thinking "outside the box."
- Students get excited about taking products to market but also want to solve social problems (e.g., poverty, hunger, energy, climate change). Such problems provide a purpose and also teach students about working in teams and across disciplines, since most cannot be solved by a single individual with expertise in a single area. Identify problems with global impact and empower students to solve one by providing the needed tools/skills.
- Encourage larger universities to implement programs and courses that educate to innovate and serve as a model for other institutions.
- *Opportunities for leverage:* (1) Government agencies can use innovation as leverage for funding. (2) Reward those who are really interested—celebrate and provide discretionary funding to them. (3) Offer faculty credit for extracurricular work and/or incentives to include innovation in their teaching. (4) Provide/publicize prizes, competitions, and challenges for students. (5) If a university president focuses on innovation, it will move the institution.
- *Suggestions for the National Academy of Engineering:* (1) Define competency and the criteria for designating a person "credentialed in innovation" (as distinct from entrepreneurship). (2) Recommend metrics and identify best practices for universi-

[2] The group cited the experience at a university where students were presented with the following challenge: "These are the five biggest questions modern chemistry can't solve now. What do you need to know to solve them?" Asking this question resulted in highly innovative success among students, but the approach was not adopted by the university because the success could not be measured as a conventional skill set.

ties. (3) Make a statement encouraging action. (4) Ask President Mote to deliver his speech at each engineering school.

## Small Business

The discussions of the small business group reflected their objectives as entrepreneurs working in a changing, fast-paced, competitive environment. Although their conception of innovation is heavily dependent on market success, they note that an entrepreneur is only one type of innovator.

According to this group, many of the obstacles to fostering innovation can be traced to the academic world. For example, one of the biggest problems is the publication system. No venture capitalist asks for a list of publications, yet professors drive students to publish, and it is difficult to publish something that does not conform. While publishing is important for academic success and professors should encourage their students to publish, they should also encourage them to author or coauthor patents, which are other useful indicators of innovative output.

The structure in place for evaluating progress and merit in the academic world is also at odds with small business values. For example, the peer review system that is a gold standard of academic quality is not relevant in a company, where a program manager makes the decisions about projects. In academia professors often shy away from risk because "failure" may hurt their chances of attaining tenure; this challenge could be solved by using different evaluative measures. The group also called for ways to reward professors whose students drop out to do startups or go on to achieve worthy accomplishments in nonacademic endeavors. They should be encouraged to conduct diverse projects, some with specific goals and some with broader goals.

The academic system's promotion of collaboration (or lack thereof) is also problematic. Universities stress individual success, at both the faculty and graduate level; some companies are like this, but values across companies vary. The ability to work in a team can help individuals learn how to communicate their ideas and get buy-in. Students with these abilities will better present themselves and their work at conferences and will work more effectively on project teams, whether in academia or in industry. Success in either setting can also be fostered by linking innovation and entrepreneurship, by bringing business into academia—for example, through opportunities for academics to present their ideas and dissertations to businesspeople, and in forums where businesspeople and academics pitch ideas and note the differences between the presentations.

Last, academic funds need to be allocated so that students have full access to resources—for example, if scanning is free, more students will use scanners and thus be able to share their ideas with others.

### *Takeaways*

- The current educational paradigm falls short in creating an environment for innovation. What happens before kids get to college? Problem-solving skills should be developed at the primary school level.

- Small businesses are innovating regularly and educators may be able to learn from them, so integrating the two spheres may be beneficial.
- In terms of collaborative efforts, schools are good at teaching how to be in a team, but not how to be in a winning team. A sense of urgency must be instilled in students, appropriate motivation must be fostered, proper incentives to innovate must be in place, and the team must be aligned around the goal.
- Informal interactions can be beneficial, as a formal environment may encourage "too much politeness."
- There is concern about the scalability of implementing ideas for educating to innovate. How can a certain practice or environment be applied to tens of thousands of students at a typical university?
- Innovative environments are significantly more important than producing individual innovators; an innovative environment will train individuals to improve whatever type of organization they are a part of (e.g., by asking "Can this task or process be done better?") independent of their role in an innovative team. This is important, because not everyone has the same caliber/skill in innovating, but everyone can contribute to innovative efforts.
- It's important to get the incentives right: if the motivation (from university, business, government) is not toward but away from innovation, innovation won't happen.

### *Next Steps and Further Research*

- *Further research:* Develop case studies of both success and failure among innovators. How do they define an outcome? How do they deal with the process of failure/recovery? How can resiliency be fostered after failure?
- *Further research:* How do innovators collaborate? What are the attributes of a winning team? How is it structured?
- *Further research:* Determine whether current organizational structures at universities are conducive to fostering innovation and its education.
- *Further research:* Assess the number of spinouts, how long it takes to complete licensing agreements between business and university, and who makes the most money from royalties. (It is more important for the country to get use of the products than for the university to get royalties.)
- *Further research:* Develop metrics to measure the success of incorporating innovation into curricula.
- *Further research:* Determine the role of open-source technology, such as online classes and other Internet tools, in educating to innovate.
- Improve communication among all stakeholders.
- Encourage universities and small businesses to collaborate; for example, small businesses can contribute with ideas for master's and doctoral degree students. Such collaboration would benefit both the business and the students, in part by helping to bridge theoretical and real-world knowledge, and it would benefit the university by contributing to the success of its students in getting jobs and contributing

to society. University departments should have requirements to ensure that each business project is suitable and fits into the academic program.
- Use challenges and competitions to engage students, by, for example, giving them a real-world problem to solve.
- Remove the headaches (e.g., health insurance) that come with hiring students and make it easier to hire graduates.
- University technology transfer rewards are an impediment; instead of trying to license patents, let a small business take the patent without having to pay a licensing fee, and let the university get part of the royalties or an equity position.
- Create a compelling narrative why universities should develop an environment that fosters innovation.
- *Suggestion for the National Academy of Engineering:* Study relations between universities and small business to identify best practices, fair compensation, models of IP agreements, and so forth.

The breakout group also offered suggestions for increasing the impact of this monograph and project:

- Write a good article in a journal with high visibility.
- Promote the findings with policymakers and at various levels (e.g., state, community).
- Demonstrate that the implications of the study are practical and implementable by offering a how-to guide with case studies of success.

## K–12 Education

The members of this group focused on the shortcomings of the current K–12 education system and advocated for a complete restructuring of the educational system to meet the goal of fostering innovation. They placed a strong emphasis on creating an environment capable of facilitating the development of skills necessary to innovate. They wanted detailed accounts of innovator experiences throughout school so that they could understand how to incorporate such experiences into teaching methods.

The discussion focused on determining the criteria that should be used to find new paradigms for innovation and on understanding what new elements need to be considered in education for innovation.

To define new paradigms that foster innovation, methods of measurement (including longitudinal measurements) need to be established. Was innovation fostered? If so, how is this known? Both the results and the process must be evaluated, so that there is recognition not only for the product of the innovation but also for following an innovative path. Tangible short- and long-term measures of success should be considered, and should take account of both group and individual performance. For example, did the group collectively achieve what it set out to do? Was a decision point reached within a project team? It may also be helpful to compare school/program graduates with a baseline cohort.

Among the criteria to consider for an education paradigm are the "human side of innovation" and the importance of the humanities in design, as distinct from traditional engineering undergraduate programs in which the courses are tightly proscribed in the first two years. Learning from the arts can foster creativity and improvisation and help students learn to value divergent and convergent thinking. Innovators should also be able to understand and articulate the value added of innovation. Courses in ethics and humanities could enable students to understand and articulate the value of their innovative ideas in a larger, societal context. The development of these skills can be facilitated at a younger age by helping students recognize what they really care about; for example, as at Olin College, young students could be asked to identify a group of people they would like to help and learn more about the group to understand how best to connect their innovative efforts and impacts. It was broadly agreed that the paradigms should ensure tight integration between education and practice, and rich cross-fertilization among different fields.

In terms of elements to be considered for innovation education, the group stressed learning by doing and getting students to be comfortable with the idea of not finding immediate answers. Students must be given the freedom to generate creative ideas even if there is no short-term return or fruition. Educators, in turn, need to understand how to give students more time to innovate, balancing between providing freedom and using deadlines.

What are the most effective ways to encourage people to pursue new, unfamiliar areas? It is likely that their willingness to expand their areas of exploration will correspond to areas they are really passionate about.

Instilling a lifelong drive to learn is crucial, and complements a curriculum that fosters innovation. To that end, it is appropriate to clarify the end goals of education in general and of a given curriculum (for example, is the current purpose of educating to innovate to create jobs?).

### *Takeaways*

- Provide more opportunities for learning by doing and balance the teaching of foundations with freedom (e.g., more time to innovate) and deadlines. Encourage creative ideas even if there is no short-term return or fruition of the idea. Make people comfortable with not finding immediate answers.
- There is frustration from higher education about student preparation, but the system tends to strip away what it takes to be an innovator as it processes students. And increasing standards-based expectations of the system seem to make it difficult to provide enough of the experiences that are key to becoming an innovator.
- There is a need for very specific examples of experiences and thought processes that led individuals to become innovators.

### *Next Steps and Further Research*

- *Further research:* More concrete examples and stories to enhance understanding of innovators' formative beginnings and experiences. One of these examples should be a narrative of an innovator's thought process.
- *Further research:* Who were innovators' formal and informal role models? How did they find them? When were they most significant? What was the nature of the interaction?
- *Further research:* What did the innovators value about their education and why? What frustrated them? What changes would they like to see and why? Ask them to specifically address these questions for their education in the United States, since some interviewees surely went to school abroad for at least some period of time.

The facilitator asked, "What needs to happen in K–12 in order to educate to innovate?"

- Combine innovation with the teaching of basic science through projects or open-ended labs.
- Create interdisciplinary teams to complement each other, e.g., integrating the arts with STEM subjects.
- Create strategic partnerships—for example, between small business development centers, Chambers of Commerce, universities, businesses, and economic development organizations—to develop pipelines for students to work on ideas.
- Create a pedagogy, class, framework, or method where students learn from their mistakes without being penalized. Make failure a learning experience.
- Improve preservice education for teachers.
- Create job-embedded professional development to support stronger cultures of professional growth.
- Reimagine the curriculum based on the goals we want to get out of it.
- Question or challenge the notion that education needs to be standardized.
- Introduce students to the creative process. Create spaces for tinkering and connections among people with different talents so there is cross-fertilization among tinkering projects. Google's 20 percent time was cited as an example, as well as *Invent to Learn: Making, Tinkering, and Engineering in the Classroom* (Sylvia Libow Martinez and Gary Stager, 2013).
- Get the accreditation function of state governments to agree that innovation needs to be a goal.
- Develop and distribute grade-level-specific materials called "The Educate to Innovate Curriculum," tied to science standards, with a student activity prong and a teacher professional development prong. Teachers can earn credit for taking the course. Start the curriculum in grade 2, with video accessible via You Tube. All materials should be available on the web and without cost.

- Create a series of web-based case studies, including failures, effective stories, teachers' voices, and mini-ethnologies that show what is working in specific communities.
- Invite the US Secretary of Education to workshops like this.
- Use existing models like Science Fairs and History Day, where students get feedback on their work. Introduce measures of evaluation of students and schools other than tests. In other words, use more formative evaluation of student work.
- Make assessment of student achievement a composite of methods, for example, tests and project-based efforts with community connections.
- Use art teachers as creativity coaches. Use and capitalize on what the arts teach, such as problem-based learning, valuing the process, using failure, nurturing creativity.
- Create bully protection squads to protect kids from being chastised for "being weird." Accept and celebrate difference.
- Stop evaluating teachers based on student test scores and stop limiting learning by "teaching to the test."
- Reclaim the role of the teacher so that s/he is an architect. Teachers should design learning to meet the needs of their students. Such designs for learning are transferable, although not necessarily generalizable, so make these designs available to other teachers to learn from.
- Develop or refine assessment tools to see if they are working. For example, ask students how their specific learning experiences worked.
- Adapt the curriculum to inspire or tap students' intrinsic motivation.
- Give students and teachers more time to learn (e.g., by having teachers teach fewer students).
- Involve students in speaking, writing, and designing what works for them.
- Work toward a cultural and organizational shift to reimagine a curriculum based on desired end goals.
- Consider how a scripted curriculum and federal accountability measures can be addressed to encourage education for innovation.

# Epilogue

Innovation has always flourished in the United States. With a shared conviction that the future can be consciously shaped for the better, Americans have innovated in every technological and social field imaginable, and they keep on innovating. One might say that innovation is part of American DNA, a part that has played a vital role in building a strong, diversified economy that offers amazing opportunities to its citizens.

But this innovation capacity must not be taken for granted. The study and workshop described in these pages show that it is important *and feasible* to help innovators discover their talents and contribute to the nation's capacity for innovation. Education—at all levels—is the key. With an educational culture that encourages and promotes innovation, the United States can sustain its technological leadership for generations to come.

As this monograph makes clear, educating for innovation is complicated and, in many ways, a nascent discipline. There is no "one-solution-fits-all" approach to innovation education. Efforts to promote innovation in the workplace are very different from those appropriate to a 6th grade science classroom, for example. And even in the same educational venture, students with different capabilities and strengths will need different approaches to bring out their capacity to innovate. Moreover, no models exist for evaluating innovation programs at any level, nor are there established ways of predicting the innovation capacity of a student.

This project was the first major step toward a more rigorous study of innovation and the factors that encourage and discourage it. It has yielded new, valuable insights from thoughtful discussions with 60 exceptional innovators from numerous fields. Each one of them participated in the study hoping that the richness of their experiences and thoughts could help enhance the United States' innovation capacities. From the workshop itself came lively contributions from stakeholders in industry, government, and all levels of education.

We have deliberately avoided imparting a framework to consolidate the insights and opinions from the workshop—and that, we feel, adds to this monograph's strengths. Educators and other professionals can use insights from the workshop's unedited discussions in ways that make the most sense in their environments. And that use will in turn lead to more research and a better understanding of how to help all kinds of students become innovators.

It is common to close with a "call to action" followed by a bullet-pointed list of recommendations. Perhaps in the future, when more research on educating for innovation has been done, such a list will exist. For now, however, our call to action for educators is simple: Use this monograph. Use its insights to develop "educate to innovate" programs in departments, classrooms, training courses, or even small groups of students. Develop metrics for evaluating such programs, and discuss your successes and failures with others trying to teach innovation. For leaders in academia and industry: Encourage your educators to use this monograph and develop mini-laboratories for strengthening innovation, and develop lines of communication that broaden the conversation about education for innovation.

Everyone interested in innovation can find something in this monograph to inspire them. We hope that such inspiration translates into new initiatives and partnerships to improve education for innovation—because it is clear that innovation can, indeed, be taught—and thus sustain the United States' position as an innovation leader for years to come.

# Appendix A
# Workshop Methods and Interviewee Profile

This study drew from qualitative research methods to obtain detailed data and explore the complexity of social processes. Such methods, considered inductive as opposed to deductive, help to characterize communities in a comprehensive and complex fashion and enable researchers to capture subtleties that may not be measurable via other techniques.[1]

A purposeful sampling strategy was used to select 60 successful US innovators identified by the steering committee and project team. The participants were interviewed by members of the project research team in open-ended conversations (by phone, video, or in person) that typically lasted between 30 minutes and two hours.

Interview questions were developed as a result of discussions between the project team and steering committee and were revised based on initial pilot interview results and feedback from the steering committee. The resulting 10–12 questions were adapted as necessary (using information from public sources about participants) to elicit more meaningful data. The interviews were designed to elicit narratives of personal experiences and perspectives on success in innovating and on educating to innovate.

The interviews were audio-recorded, transcribed, and confirmed with the interviewees for accuracy. Use of a qualitative data analysis program made it possible to identify themes that were common among the responses and significant to the participants. The researchers then studied and analyzed thematic patterns and interconnections among them.

The initial findings of the study were provided to the workshop participants as background information for the breakout sessions.

[1] For more information about qualitative research, the following resources are suggested: Taylor, Steven, and Robert Bogdan (1998), *Introduction to Qualitative Research Methods: A Guidebook and Resource*, chapter 3 (New York: Wiley); Seidman, Irving (2006), *Interviewing as Qualitative Research*, chapters 6–7 (New York: Teachers College Press).

## INTERVIEWEE PROFILE

Demographic information on the 60 innovators who participated in the interviews (from about 150 invitations) was obtained from public sources. Of the 60, 49 (81.7 percent) were male and 11 (18.3 percent) were female.

The interviewees were concentrated in different areas of experience and work. Figure A-1 shows the percentages of participants with experience in various sectors—academic, small business, large business, arts, federal—at some point in their career. Most (61.7 percent) had experience working in a small business.

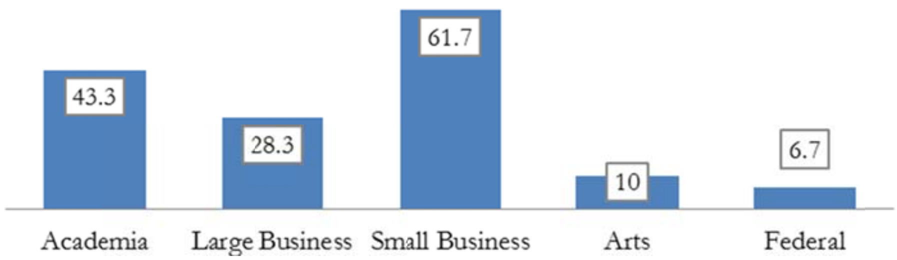


FIGURE A-1 Areas of experience across entire career (percent). Most of the interviewees have experiences in multiple areas.

# Appendix B
# Interviewee Bios

**Jad Abumrad**
Abumrad is a Lebanese-American radio host and producer. He founded and cohosts the National Public Radio program Radiolab, a show about curiosity, ideas, science, philosophy, and the human experience. Before Radiolab, he studied creative writing and music composition at Oberlin College. He wrote music for films, and reported and produced documentaries for local and national public radio programs.

**Rakesh Agrawal (NAE)**
As Winthrop E. Stone Distinguished Professor of Chemical Engineering at Purdue University, Agrawal's interest and passion are in energy production. Previously, he worked at Air Products and Chemicals, Inc., for over two decades, and was selected for the company's highest technical position, Air Product Fellow.

**David Agus**
Agus is one of the world's leading cancer doctors and a professor of medicine and engineering at the University of Southern California Keck School of Medicine and Viterbi School of Engineering, where he leads the university's Westside Cancer Center and Center for Applied Molecular Medicine. He advocates for new technologies and approaches for personalized health care, and cofounded Navigenics and Applied Proteomics with these goals in mind. He is the author of #1 *New York Times* bestseller *The End of Illness*.

**Franz Aliquo**
As a creative director/strategist at RPMGRP, Aliquo is "getting [his] hands dirty . . . developing branded film and TV content, and waxing poetic on brand consulting and marketing strategies. . . ." As the owner of ShadowGov, he cofounded StreetWars, a 3-week-long, 24/7 "watergun assassination tournament."

**Ryan Bailey**
Bailey is associate professor of chemistry at the University of Illinois at Urbana-Champaign, where he is also affiliated with the Institute for Genomic Biology. His research interests involve bioanalytical and biomaterials chemistry. His research group is developing chip-integrated arrays of photonic sensors that detect signatures of diseases at their earliest stages, thus helping clinicians choose the best personalized treatment plans.

**Laurie Dean Baird**
Baird is a strategic consultant in media and entertainment and focuses on emerging technology, social practices, and business models in the changing media landscape. She is a research fellow at the Futures of Entertainment and a strategic consultant at the Georgia Tech Institute for People and Technology.

**Sundaresh (Sundu) Brahmasandra**
Brahmasandra serves as president of NeuMoDx Molecular. Previously, he was the president of Life Magnetics, Inc., a University of Michigan spinout that developed a novel, nonmicroscope-based platform for real-time monitoring of cell growth, death, and other binding events. He was a cofounder and vice president of product development at HandyLab, Inc., which was acquired by BD for more than $275 million.

**Yoram Bresler**
Bresler is a professor in the Departments of Electrical and Computer Engineering and of Bioengineering, and research professor at the Coordinated Science Laboratory at the University of Illinois at Urbana-Champaign. He founded InstaRecon, Inc., a supplier of technology and services to imaging scanner equipment makers and supply chain partners.

**Paul Camuti**
Camuti was named senior vice president, innovation, and chief technology officer of Ingersoll Rand in 2011. He was previously president of Smart Grid Applications for Siemens Energy Inc. and president and CEO of Siemens Corporate Research. He founded the industrial software business at Siemens Energy and Automation.

**Dean Chang**
Chang is the founding associate vice president for the University of Maryland's new Academy for Innovation and Entrepreneurship and was previously director of UMD's tech ventures startup programs in the engineering school. He was CTO and vice president, Gaming Business at Immersion Corporation, a company he guided over ten years from a four-person Stanford startup to a publicly traded, world-leading licensor of haptics technology.

**Uma Chowdhry (NAE)**
Chowdhry is the chief science and technology officer emerita at Dupont, cochair of the National Research Council's Government-University-Industry Research Roundtable Council, and a member of NAE's governing council, NIST's advisory board, MIT Corporation's visiting committee, and the boards of directors for Baxter International and LORD Corporation. Prior to her retirement, she oversaw DuPont R&D globally and was responsible for formulating the strategy for R&D programs, policies, and procedures to advance DuPont's vision, competitive position, and profitability.

**Tim Cook**
Tim Cook is Apple's CEO and serves on its board of directors. As CEO, he has encouraged greater collaboration and creativity among Apple's team, which is widely regarded as the most innovative in the world. Before being named CEO in August 2011, he was Apple's chief operating officer and was responsible for the company's worldwide sales and operations. In his time at Apple, he has helped improve conditions for workers who make the company's products, and is today leading a companywide effort to use 100 percent renewable energy at all Apple facilities.

**R. Graham Cooks**
Cooks is Distinguished Professor of Chemistry at Purdue University. His interests involve construction of mass spectrometers as well as studies of their fundamentals and applications. His work on ionization methods has contributed to the ambient method of desorption electrospray ionization, which is used in tissue monitoring, forensics, and pharmaceutical applications.

**Robert Dennard (NAE)**
Dennard is a retired IBM Fellow known for inventing dynamic random access memory (DRAM) and formulating the scaling theory, making it possible to miniaturize the channel lengths of metal oxide semiconductor field-effect transistors, or MOSFETs, down to just nanometers.

**Regina Dugan**
Dugan is senior vice president of engineering at Google's Advanced Technology and Projects group (ATAP), a small band of makers and believers charged with achieving breakthrough innovations in mobile computing and accelerating the development of promising technologies to market. Prior to joining Google, she was director of the Defense Advanced Research Projects Agency (DARPA), the principal agency in the US Department of Defense for research, development, and demonstration of high-risk, high-payoff capabilities.

**Robert Fischell (NAE)**
Fischell is a physicist, inventor, and holder of more than 200 US and foreign medical patents. He has had two pioneering careers. His current career is characterized by forming several biotechnology companies to develop and refine his inventions and innovations

so that major medical companies may acquire them. Examples of his inventions are coronary stents, the implantable heart defibrillator, and a cranial implant for treating epilepsy. In his former career he helped create the modern era of space satellites.

**Michael Frenkel**
Frenkel is fellow and director of the Thermodynamics Research Center (TRC) at the US National Institute of Standards and Technology (NIST) in Boulder. He is also Honorary Professor at the Colorado School of Mines, École Nationale Supérieure des Mines de Paris, and Changsha University of Science and Technology (China). His research interests cover a broad range of scientific areas such as phenomenological and statistical thermodynamics, information management and communication, and software expert systems. In the last 15 years, he led the effort at TRC in the development and software implementation of the concept of *global information systems in science* in application to the field of thermodynamics.

**Ashifi Gogo**
Gogo is the CEO and founder of Sproxil, Inc. Under his leadership, the company developed its award-winning mobile product authentication (MPA) technology. He earned a PhD in electrical engineering from the Thayer School of Engineering at Dartmouth College, and is Dartmouth's first-ever PhD Innovation Fellow.

**Anoop Gupta**
Gupta is a distinguished scientist at Microsoft Research and works on cross-disciplinary research that has potential for large business or societal impact. Before joining Microsoft, he was a professor of computer science and electrical engineering at Stanford University for 11 years; while there, he and his students founded VXtreme Inc., a Microsoft-acquired company.

**Kalyan Handique**
Handique cofounded HandyLab, a startup whose "Jaguar" technology revolutionized the speed and accuracy at which infections are detected. He is now CEO of DeNovo Sciences, whose cancer research and diagnosis platform offers an alternative to painful and invasive biopsies and could one day make it possible to detect cancer before primary tumors are discovered.

**Doug Hart**
Hart is an MIT professor of engineering and a principal investigator in the Hatsopoulos Microfluids Laboratory. He is an inventor, cofounder, and board member of three venture-funded companies, and has a long history of successful inventions both in and outside of academia. His research interests include image processing and optical diagnostics relating to health and the environment.

**John Hennessy (NAE)**
Hennessy serves as president of Stanford University and is well known for pioneering the RISC processor architecture and for leadership in computer engineering and higher education. He is one of the founders of MIPS Computer Systems Inc. As provost of Stanford University, he was instrumental in fostering interdisciplinary activities in the biosciences and bioengineering, and oversaw improvements in faculty and staff compensation.

**Brian Hinman**
Hinman is a venture partner at Oak Investment Partners, where he focuses on investments in information technology and clean energy. He cofounded PictureTel, Polycom, 2Wire, and Mimosa Networks, where he currently serves as CEO. Having attended the University of Maryland as an undergraduate, he now sponsors the university's Hinman Campus Entrepreneurship Opportunities (CEO) Program.

**David Hornik**
Hornik is a general partner at August Capital. He invests broadly in information technology companies, with a focus on enterprise application and infrastructure software and consumer facing software and services. He was previously an intellectual property and corporate attorney who represented high-tech startups in all aspects of their formation, financing, and operations.

**Alan Heeger**
Heeger is a professor of chemistry and biochemistry at the University of California at Santa Barbara. He has received the Nobel Prize in Chemistry and is known for his pioneering research in and cofounding of the field of semiconducting and metallic polymers. He has more than 800 publications in scientific journals and more than 50 patents. He founded and cofounded several companies, one of which, UNIAX, was acquired by DuPont in 2000.

**Jack Hughes**
Hughes is the founder of TopCoder, which was acquired by Appirio in 2013. He founded TopCoder on the premise that talent and skill are the determinant factors in the quality and utility of software, which is central to the global economy. Previously he served as chairman at Tallan, which under his lead was recognized as one of the fastest-growing technology companies in North America four years in a row by Deloitte & Touche.

**Prashant K. Jain**
Jain is an assistant professor in chemistry at the University of Illinois at Urbana-Champaign, affiliated with the Materials Research Lab, the Department of Physics, and the Beckman Institute. His research interests are in nano-optics and molecular imaging with the goal of understanding and controlling energy transport, light-matter interactions, and chemical transformations on nanometer-length scales.

**Mary Lou Jepsen**
Jepsen is head of the Display Division at Google X. She is also the founder and former CEO of Pixel Qi, a manufacturer of high-performance, low-power, sunlight-readable screens for mobile devices, and cofounder and former CTO of One Laptop per Child.

**Frans Johansson**
Johansson is an innovation speaker, entrepreneur, and author of the book *The Medici Effect*, on innovation. He also founded the Medici Group, an innovation and strategy consulting firm that seeks to help companies drive growth, transform leaders, and create a self-sustaining culture of innovation that can withstand even the most volatile markets.

**Karen Kerr**
Kerr is the senior managing director for advanced manufacturing at GE Ventures, General Electric, where she is leading a team focused on supporting the advanced manufacturing ecosystem and making strategic investments and developing partnerships in this area. Previously, she served as senior director of new ventures and alliances at the University of Southern California Stevens Center for Innovation, where she was responsible for accelerating the formation of startups out of university research. She founded Agile Equities LLC, a venture development company specializing in emerging technology companies.

**Aaron Koblin**
Koblin is best known for his innovative uses of data visualization and crowdsourcing. He currently holds the position of creative director of the Data Arts team in Google's Creative Lab. His team worked with Arcade Fire to produce an online music video that allows viewers to incorporate images of their home neighborhood into the experience using Google Street View.

**Robert S. Langer (NAE)**
Langer is the David H. Koch Institute Professor at MIT, the highest honor that can be awarded to a faculty member, and one of the few people elected to all three US National Academies (the National Academy of Sciences, National Academy of Engineering, and Institute of Medicine). His research is at the interface of medicine, materials science, and chemical engineering. He has authored more than 1,200 articles and has over 1,000 issued and pending patents worldwide.

**Yo-Yo Ma**
Ma is an American cellist. He began to study the instrument at the age of 4, and his discography numbers over 90 albums, including more than 17 Grammy Award winners. One of his goals is the exploration of music as a means of communication and as a vehicle for the migration of ideas across cultures throughout the world. To that end, he founded Silkroad, a nonprofit organization that, through performance, the creation of new music, cultural partnerships, education programs, and cross-disciplinary collaborations, seeks to create meaningful change at the intersection of the arts, education, and business.

**Mary Ann Meador**
Meador is senior chemical engineer at the NASA Glenn Research Center in the Materials and Structures Division. She is also an adjunct professor of polymer engineering at the University of Akron and an editor for *ACS Applied Materials and Interfaces*.

**Robert Metcalfe (NAE)**
Metcalfe is professor of innovation and Murchison Fellow of Free Enterprise in the University of Texas at Austin's Cockrell School of Engineering. He invented Ethernet, founded 3Com Corporation, was CEO of IDG's InfoWorld Publishing Company and wrote a weekly column for 10 years, and is a partner emeritus at Polaris Partners.

**Bernard Meyerson (NAE)**
Meyerson is an IBM Fellow, IBM's vice president for innovation, and drives corporate initiatives in IBM's Corporate Strategy Function. He has been part of the IBM family since 1980, led the development of silicon germanium and other high-performance semiconductor technologies, and held a wide range of positions in broad executive management.

**Richard K. Miller (NAE)**
Miller is the president and first employee of Olin College of Engineering. Previously, he was dean of the College of Engineering at the University of Iowa. He has consulted to the World Bank for establishing new universities and served on several academic, federal, and industrial advisory boards and committees. He is interested in innovation in higher education and is a frequent speaker on engineering education.

**Thomas Miller**
Miller is executive director of the Entrepreneurship Initiative, initiator of the Engineering Entrepreneurs Program, and vice provost for Distance Education and Learning Technology Applications (DELTA) at North Carolina State University, where he is also a professor in the Department of Electrical and Computer Engineering.

**Chad Mirkin (NAE)**
Mirkin is director of the International Institute for Nanotechnology and the George B. Rathmann Professor of Chemistry, and professor of chemical and biological engineering, biomedical engineering, materials science and engineering, and medicine at Northwestern University. He is best known for his discovery, synthesis, and development of spherical nucleic acids (SNAs) and the biodetection schemes and therapeutics approaches that have derived from them, the invention of Dip-Pen nanolithography, and contributions to supramolecular chemistry and nanoparticle synthesis. He has founded multiple companies, which have commercialized over 1,700 nanotechnology products for the life science and semiconductor industries.

**Katherine T. Moortgat**

Moortgat is passionate about enabling innovation. As a partner at Mohr Davidow Ventures, and as the founding director of UC San Francisco's hub for entrepreneurship, she has led initiatives fostering the commercialization of technologies originating in universities and national labs. She has served on the board of councilors for the USC Stevens Institute for Innovation, and has mentored other universities in spurring innovation. She currently advises growth-stage startups as a business consultant.

**David Morse (NAE)**

Morse is the executive vice president and chief technology officer at Corning, managing 3,000 scientists and engineers and a budget of $800 million. He is a member of the National Chemistry Board and the Dow-Corning Board of Directors. He started at Corning Incorporated in 1976 as a glass composition scientist and has developed and patented many products in ophthalmics, optics, and technical glass.

**Rodney Mullen**

Mullen is considered the most influential skateboarder in the history of skateboarding. He invented the majority of flatground ollie and flip tricks, including the kickflip and 360-flip. He is also an entrepreneur, inventor, and public speaker who articulates what it means to be a skateboarder and push the limits of one's craft.

**Beth Simone Noveck**

Noveck directs the Governance Lab and its MacArthur Research Network on Opening Governance. She is the Jacob K. Javits Visiting Professor at New York University's Robert F. Wagner Graduate School of Public Service, a visiting professor at the MIT Media Lab, and a professor of law at New York Law School. She served in the White House as the first United States deputy CTO and director of the White House Open Government Initiative. Among projects she's designed or collaborated on are Unchat, the Do Tank, Peer to Patent, Data.gov, Challenge.gov, and the Gov Lab's Living Labs and training platform.

**Alyssa Panitch**

Panitch is the Leslie A. Geddes Professor of Biomedical Engineering at Purdue, where she led a team that discovered a class of biomimetic molecules that promote healthy tissue healing and regeneration. She was previously associate professor of bioengineering at Arizona State University and has launched three successful startups.

**Stuart Parkin (NAE)**

Parkin is an IBM Fellow and manager of the Magnetoelectronics group at IBM Research–Almaden as well as a consulting professor in the Department of Applied Physics at Stanford University, where he is also director of the IBM-Stanford Spintronic Science and Applications Center. He is researching new structures for use as spin transistors and spin-logic devices that may enable a new generation of low-power electronics.

**Mark Randall**
Randall is chief strategist, advanced technology, at Adobe. He speaks and teaches frequently on entrepreneurship, innovation, and strategy. He is a serial entrepreneur whose nearly 20-year career includes three high-tech startups and over a dozen products that have together sold over a million units and are used by half the Fortune 500 companies, all branches of the US government, and thousands of schools around the world.

**Carmichael Roberts**
Roberts is a general partner at North Bridge Venture Partners, where he predominantly invests in companies that make products involving chemistry, materials science, and materials engineering. He is also the cofounder and chair of the board of Diagnostics for All and 480 Biomedical, Inc., and cofounder and lead director of Arsenal Medical.

**John Rogers (NAE)**
Rogers holds a primary appointment with the Department of Materials Science and Engineering at the University of Illinois at Urbana-Champaign, where he directs the Seitz Materials Research Laboratory and holds the Swanlund Chair, the highest chaired position at the university. His research includes fundamental and applied aspects of nano- and molecular-scale fabrication as well as materials and patterning techniques for unusual electronic and photonic devices, with an emphasis on biointegrated and bioinspired systems.

**Donald R. Sadoway**
Sadoway is the John F. Elliot Professor of Materials Chemistry at the Massachusetts Institute of Technology. His research seeks to establish the scientific underpinnings for technologies that make efficient use of energy and natural resources in a sound manner. He is an expert on batteries, and the overarching theme of his work is electrochemistry in nonaqueous media.

**Amy Salzhauer**
Salzhauer founded Ignition Ventures, a firm that matches a network of world-class researchers with a select group of business strategy consultants who focus on technology strategy and new venture creation. She is a specialist in technological innovation and entrepreneurship, and has served as CEO of multiple startup companies.

**Maria Scileppi**
Scileppi leads 72U, a 72 and Sunny program designed to cultivate the next generation of leaders for the creative industry. She has served as art director at Y&R NY and director at the Chicago Portfolio School, and worked on a collaborative storytelling project, "Journey Home," based on shared experiences.

**Ivan Seidenberg**
Seidenberg is the former chair and CEO of Verizon Communications. He worked in the communications industry for more than 45 years, and is known for steering the merger of Bell Atlantic and NYNEX in 1997 and the Bell Atlantic merger with GTE in 2000. He also led efforts to form Verizon Wireless.

**Varun Soni**
Soni is the dean of religious life at the University of Southern California and the first Hindu to serve as the chief religious leader of an American university. He is also an adjunct professor in the USC School of Religion and a University Fellow at the USC Annenberg Center on Public Diplomacy. Before joining USC, he taught in the Law and Society Program at UC Santa Barbara.

**Dwayne Spradlin**
Spradlin is head of the Health Data Consortium, a major nonprofit private/public initiative supported by the Robert Wood Johnson Foundation, US Department of Health and Human Services, and others. He was previously president and CEO of InnoCentive, president of Hoovers Online, president and COO of StarCite Inc., senior vice president at VerticalNet Inc., and director at PriceWaterhouseCoopers.

**Nina Tandon**
Tandon studies electrical signaling in the context of tissue engineering. She is an adjunct professor of electrical engineering at the Cooper Union, and works as an electrical and biomedical engineer at Columbia University's Laboratory for Stem Cells and Tissue Engineering. She is cofounder and CEO of EpiBone, a company that uses scans of patients' bone defects and their own stem cells to engineer personalized bone grafts.

**Richard Tapia (NAE)**
Tapia, a professor in the Department of Computational and Applied Mathematics at Rice University, is best known for his computational and mathematical science research and as a national leader in education and outreach programs. For these sustained efforts, he was awarded the National Medal of Science, the highest honor bestowed by the US government on scientists, engineers, and inventors.

**Herbert Holden Thorp**
Thorp is a chemist, entrepreneur, inventor, musician, and professor and has cofounded multiple biotechnology startups. He is provost at the Washington University in St. Louis, and was previously chancellor of the University of North Carolina at Chapel Hill. He is an inaugural member of the National Advisory Council on Innovation and Entrepreneurship and serves on the US Manufacturing Competitiveness Initiative for the Council on Competitiveness.

**Luis von Ahn**

An entrepreneur and associate professor of computer science at Carnegie Mellon University, von Ahn is considered one of the pioneers of crowdsourcing, or as he calls it, human computation. His goal is to build systems that combine humans and computers to solve large-scale problems that neither can solve alone. His projects include CAPTCHA, the ESP Game, GWAP, reCAPTCHA, and Duolingo.

**Andy Walshe**

Walshe is Red Bull's High Performance Director, and he seeks to develop a greater understanding of the "human potential" construct and its application toward the betterment of society. He specializes in human performance at the highest levels of execution and the development of talent in a strategic framework to optimize the potential of individuals, teams, and organizations.

**George Whitesides (NAE)**

Whitesides is a chemist and the Woodford L. and Ann A. Flowers University Professor at Harvard University, where he has been a faculty member since 1982. His current research spans many areas, including molecular self-assembly, surface and nanoscience, low-cost diagnostics, water, simplicity, and the origin of life.

# Appendix C
# Workshop Agenda

## Tuesday, October 22, 2013

### National Academy of Sciences Building, 2101 Constitution Avenue NW

6:00 PM Reception and Dinner

7:15 PM Speaker: Herbert Holden Thorp, Provost, Washington University, St. Louis
Title: Building a Culture of Innovation and Entrepreneurship in Higher Education

## Wednesday, October 23, 2013

### National Academy of Sciences Building, 2101 Constitution Avenue NW

8:00 AM Arden Bement and Deba Dutta

- Welcome and ETI project background
- Workshop goals and objectives
- Preliminary findings from the ETI study

8:15 C. D. Mote, Jr., President, NAE
Title: Vision for Universitywide Innovation and Entrepreneurship

8:45 Breakout session I *(four 90-min sessions in parallel)*
Brief discussion of key findings from the study

- Address the question given
- Prioritize skills, experiences, and environments

10:15 Break

10:30 Breakout session II *(four 60-min sessions in parallel)*[1]

- What are the takeaways from breakout session I?
- What more would you like to learn from the interview analysis?

11:30 Report out by sector groups (plenary session; 5–6 min per group)

12 Noon Lunch (buffet); Networking and informal discussions

1:15 PM Breakout session III *(four 90-min sessions in parallel)*

- Discuss next steps for action items from breakout sessions I and II
- Identify road blocks, points of leverage, stakeholders, etc.

2:45 Break

3:00 Report out (Plenary session; 5–6 min per group)

3:30 Tom Kalil, Deputy Director for Technology and Innovation, White House Office of Science and Technology Policy

3:45 Arden Bement and Deba Dutta

- Closing remarks
- Participant feedback (individual)

4:00 Workshop adjourn

[1] For breakout sessions II and III participants reconvened in four sector groups: academia, K–12 education, large business, and small business. Participants from professional societies, federal organizations, and media/arts were distributed among these groups (assignments were announced at the workshop).

# Appendix D
# Workshop Participant Bios

**Ashok Agrawal – American Society of Engineering Education**
Agrawal is managing director for professional development at the American Society for Engineering Education (ASEE). He was previously vice president for academic affairs at St. Louis Community College–Florissant Valley.

**Rakesh Agrawal (NAE) – Purdue University**
As Winthrop E. Stone Distinguished Professor of Chemical Engineering at Purdue University, Agrawal's interest and passion are in energy production. Previously, he worked at Air Products and Chemicals, Inc., for over two decades, and was selected for the company's highest technical position, Air Product Fellow.

**Franz Aliquo – RPMGRP/ShadowGov**
As a creative director/strategist at RPMGRP, Aliquo is "getting [his] hands dirty . . . developing branded film and TV content, and waxing poetic on brand consulting and marketing strategies. . . ." As the owner of ShadowGov, he cofounded StreetWars, a 3-week-long, 24/7 "watergun assassination tournament."

**Laurie Dean Baird – Laderium Media Group**
Baird is a strategic consultant in media and entertainment and focuses on emerging technology, social practices, and business models in the changing media landscape. She is a research fellow at the Futures of Entertainment and a strategic consultant at the Georgia Tech Institute for People and Technology.

**Kenneth Bernstein – Eleanor Roosevelt High School, Greenbelt, MD**
Bernstein is a retired National Board Certified social studies teacher who was a 2010 *Washington Post* Agnes Meyer Outstanding Teacher. Nationally known for his blogging as "teacherken" at Daily Kos and elsewhere, he served until his retirement as the lead building representative (NEA) at Eleanor Roosevelt High School in Greenbelt, MD.

**Yoram Bresler – University of Illinois at Urbana-Champaign**
Bresler is a professor in the Departments of Electrical and Computer Engineering and of Bioengineering, and research professor at the Coordinated Science Laboratory at the University of Illinois at Urbana-Champaign. He founded InstaRecon, Inc., a supplier of technology and services to imaging scanner equipment makers and supply chain partners.

**Keith Buffinton – Bucknell University**
Buffinton is dean of the College of Engineering and professor of mechanical engineering at Bucknell University. He is also a member of the executive board of the ASEE Engineering Deans Council (EDC) and cochair of the ASEE EDC Undergraduate Experience Committee.

**Susan Butts – Susan Butts Consulting**
Butts was senior director of External Science and Technology Programs at Dow Chemical Company, where she held various positions for three decades. She has served as president of the Council for Chemical Research (CCR) and is now a consultant in science and technology policy, university-industry-research partnerships, technology transfer, and commercialization.

**Paul A. Camuti – Ingersoll Rand**
Camuti was named senior vice president, innovation and chief technology officer of Ingersoll Rand in 2011. He was previously president of Smart Grid Applications for Siemens Energy Inc. and president and CEO of Siemens Corporate Research. He founded the industrial software business at Siemens Energy and Automation.

**Dean Chang – University of Maryland, College Park**
Chang is the founding associate vice president for UMD's new Academy for Innovation and Entrepreneurship and was previously director of the university's Mtech Venture-Accelerator and Technology Advancement programs. He was CTO and vice president, Gaming Business at Immersion Corporation, a company he guided over ten years from a four-person startup to a publicly traded, world-leading licensor of haptics technology.

**Sandra K. Chhabra – Thomas Jefferson High School for Science and Technology, Alexandria, VA**
Chhabra has been a chemistry teacher at Thomas Jefferson High School for Science and Technology for the past 26 years. Born and raised in Thailand, she speaks, reads, and writes four languages.

**Uma Chowdhry (NAE) – DuPont**
As retired DuPont chief science and technology officer, Chowdhry oversaw DuPont R&D globally and was responsible for formulating the company's strategy for R&D programs, policies, and procedures to advance its vision, competitive position, and profitability.

**Peter Clancy – Illinois Mathematics and Science Academy, Aurora**
Clancy teaches physics and engineering at IMSA, and is in his $18^{th}$ year of teaching physics, mathematics, engineering, and chemistry at the high school or community college level. Before becoming an educator, he spent 14 years working at IBM, the last 5 of which were in environmental engineering.

**Gary Cowger – GLC Ventures LLC**
Cowger is chair and CEO of GLC Ventures LLC, a management consultancy on business, manufacturing, and technology strategy. He had a 45-year career at General Motors and, when he retired, was group vice president of Global Manufacturing and Labor Relations.

**Manuel De Ponte – The Aerospace Corporation**
De Ponte is senior vice president of Aerospace's National Systems Group, which supports the national security space and intelligence community in the acquisition, launch, and orbital operation of advanced technology space systems in their ground data stations.

**Frederick Dillman – Unisys**
As CTO of Unisys Corporation, where he has worked since 1980, Dillman oversees research and deployment of new technologies in IT infrastructure, application services, security technologies, and end user services. He is currently leading new initiatives in cloud computing, social networking technologies, new security technologies, and application modernization and modeling capabilities.

**Graham Doxey – Global Learning U**
Doxey is the founder and CEO of Global Learning U, higher education designed for the growing global middle class through partnerships with academic institutions and employers. He also founded and was president of Neumont University, and holds leadership positions at various businesses.

**Joan Ferrini-Mundy – National Science Foundation**
Ferrini-Mundy is assistant director of the NSF Directorate for Education and Human Resources (EHR). She has served the Foundation in a number of capacities since 2007, including as inaugural director of the EHR Division of Research on Learning in Formal and Informal Settings. She cochairs the Strategic Plan workgroup of the National Science and Technology Council Committee on STEM Education.

**Robert E. Fischell (NAE) – Fischell Biomedical LLC**
Fischell is a physicist, inventor, and holder of more than 200 US and foreign medical patents. He has had two pioneering careers. His current career is characterized by forming biotechnology companies to develop and refine his inventions and innovations so that major medical companies may acquire them. Examples of his inventions are coronary stents, the implantable heart defibrillator, and a cranial implant for treating epilepsy. In his former career he helped create the modern era of space satellites.

**Patricia Fuglestad – Dryden Elementary School, Arlington Heights, IL**
For nearly three decades Fuglestad has been exploring ways to use new technologies to support, enhance, and transform teaching and learning in the art classroom. In 2007 she launched Art Education 2.0, a social network that aims to connect art classrooms around the globe, enabling art teachers and students to collaborate on shared artistic and educational goals.

**Kaigham (Ken) Gabriel – Motorola Mobility**
Gabriel is a corporate vice president at Motorola Mobility and deputy of Advanced Technology and Projects (ATAP). He was previously deputy director of DARPA and founder, chair, and chief technical officer of Akustica, a semiconductor company that commercializes microelectromechanical system (MEMS) sensors for consumer electronics products.

**Anoop Gupta – Microsoft**
Gupta is a distinguished scientist at Microsoft Research and works on cross-disciplinary research that has potential for large business or societal impact. Before joining Microsoft, he was a professor of computer science and electrical engineering at Stanford University for 11 years; while there, he and his students founded VXtreme Inc., a Microsoft-acquired company.

**Kalyan Handique – DeNovo Sciences**
Handique cofounded HandyLab, a startup whose "Jaguar" technology revolutionized the speed and accuracy at which infections are detected. He is now CEO of DeNovo Sciences, whose cancer research and diagnosis platform offers an alternative to painful and invasive biopsies and could one day make it possible to detect cancer before primary tumors are discovered.

**Doug Hart – Massachusetts Institute of Technology**
Hart is an MIT professor of engineering and a principal investigator in the Hatsopoulos Microfluids Laboratory. He is an inventor, cofounder, and board member of three venture-funded companies, and has a long history of successful inventions both in and outside of academia. His research interests include image processing and optical diagnostics relating to health and the environment.

**Eric Hawker – Illinois Mathematics and Science Academy**
Hawker's interests include astrophysics, particle physics, engineering, technology, fencing, soccer, science fiction, and self-paced and proficiency-based education. He joined the IMSA faculty to pursue his passion for teaching and physics education. He worked previously at Western Illinois University and the Fermi Lab.

**Joseph Helble – Dartmouth College**
Helble is dean and professor at the Thayer of School of Engineering at Dartmouth College where, among other things, he has been instrumental in establishing the PhD

Innovation Program. His research interests include environmental impacts of fossil energy use with emphasis on mercury, particulate matter, air pollution control, $CO_2$ capture, and combustion-derived pollution.

**Prashant K. Jain – University of Illinois at Urbana-Champaign**
Jain is an assistant professor in chemistry at UIUC, affiliated with the Materials Research Lab, the Department of Physics, and the Beckman Institute. His research interests are in nano-optics and molecular imaging with the goal of understanding and controlling energy transport, light-matter interactions, and chemical transformations on nanometer-length scales.

**Thomas Kalil – White House Office of Science and Technology Policy**
Kalil is deputy director for policy at OSTP as well as senior advisor for science, technology, and innovation of the National Economic Council. He previously served as special assistant to the chancellor for science and technology at UC Berkeley, where he developed major new multidisciplinary research and education initiatives.

**Pramod Khargonekar – National Science Foundation**
As assistant director, Khargonekar leads NSF's Engineering Directorate in investing in engineering research and education, innovation, and developing the next-generation engineer. He is also Eckis Professor of Electrical and Computer Engineering at the University of Florida.

**Elizabeth Kisenwether – Pennsylvania State University**
An expert in engineering design, product design, innovation and entrepreneurship, and engineering education assessment, Kisenwether is codirector of the Lion Launch Pad–Center for Penn State Student Entrepreneurship and director of PSU's engineering entrepreneurship (E-SHIP) minor. She is a member of the ASEE and has chaired its Entrepreneurship Division Program.

**Aaron Koblin – Google**
Koblin, creative director of the Data Arts team in Google's Creative Lab, is best known for his innovative uses of data visualization and crowdsourcing. His team at Google worked with Arcade Fire to produce an online music video that allows viewers to incorporate images of their home neighborhood using Google Street View.

**Gita Krishnaswamy – Kent School District, WA**
Krishnaswamy is the K–12 curriculum coordinator for science and health/fitness in Washington's Kent School District and a leader in K–12 teaching and learning, secondary science curriculum development, and professional development in science literacy and constructivist pedagogy. She has worked for both public and private school systems in Illinois, California, and Washington and is an experienced public health practitioner.

**James Lightbourne – National Science Foundation**
Lightbourne is a senior advisor in the Office of the Director and acting director of the NSF Office of Equal Opportunity Programs. Previous NSF positions include section head in the Division of Undergraduate Education, director of the Division of Graduate Education, and senior advisor for the Directorate for Education and Human Resources.

**Marina Lopez – Spry Elementary Community School, Chicago**
A visual arts specialist, Lopez works at Spry Community School as a magnet cluster lead teacher. She is a member of the Teacher Advisory Committee with the Museum of Contemporary Art Chicago and a program committee member for Chicago Arts Partnership in Education (CAPE).

**Cheryl Martin – ARPA-E**
As deputy director of the Advanced Research Project Agency–Energy, Martin is responsible for oversight of the agency and also leads its Technology-to-Market program, which helps breakthrough technologies find success in the marketplace.

**Nancy Martin – General Electric**
Martin works at GE's Global Research Center in Niskayuna, NY, where she manages (designs and delivers) technical education for the company, including the 1,000-person Edison Engineering program, where she started her career over 30 years ago. Most of her 17 roles at GE have been in management of engineering and research.

**Ned McCulloch – IBM**
As global issue manager for skills development and education in IBM's Governmental Program, McCulloch manages the company's public policy for skills and education across the globe. He was previously counsel to US Senator Joseph Lieberman for health and social policy, and also worked as a lobbyist on health and public employee issues for the Service Employees International Union.

**Thomas McKeeff – Sproxil**
Currently a business analyst at Sproxil, McKeeff is a cognitive neuroscientist by training. His research focuses on the cortical and cognitive mechanisms that underlie perception, attention, action, and awareness.

**Mary Ann Meador – National Aeronautics and Space Administration**
Meador is a senior chemical engineer at the NASA Glenn Research Center in the Durability in Coatings Branch. She has also worked at the NASA Lewis Research Center in both the Materials Division and the Polymers Branch, and is an adjunct professor of polymer engineering at the University of Akron.

**Robert Metcalfe (NAE) – University of Texas at Austin**
Metcalfe is professor of innovation and Murchison Fellow of Free Enterprise in the University of Texas at Austin's Cockrell School of Engineering. He invented Ethernet, founded 3Com Corporation, was CEO of IDG's InfoWorld Publishing Company and wrote a weekly column for 10 years, and is a partner emeritus at Polaris Partners.

**Richard K. Miller (NAE) – Olin College of Engineering**
Miller is the president and first employee of Olin College of Engineering. Previously, he was dean of the College of Engineering at the University of Iowa. He has consulted to the World Bank for establishing new universities and served on several academic, federal, and industrial advisory boards and committees. He is interested in innovation in higher education and is a frequent speaker on engineering education.

**Thomas Miller – North Carolina State University**
Miller is executive director of the Entrepreneurship Initiative, initiator of the Engineering Entrepreneurs Program, and vice provost for Distance Education and Learning Technology Applications (DELTA) at NC State, where he is also a professor in the Department of Electrical and Computer Engineering.

**KT Moortgat – Startup and Business Development Consulting**
Formerly a partner of Mohr Davidow Ventures, Moortgat led the investment team's initiatives fostering the commercialization of technologies that originate in universities and national labs. She is a member of the board of councilors for USC's Stevens Institute for Innovation, using her experience to help university entrepreneurs.

**Samuel Naffziger – Advanced Micro Devices (AMD)**
As an AMD corporate fellow, Naffziger drives the company's low-power design initiatives. He has also been active in the growth of the AMD technical community internally. He led the Itanium design team at Intel for eight years before transferring to AMD.

**Jeffrey Owens – Delphi**
As CTO and executive vice president, Owens leads Delphi's innovation strategies and is responsible for its enterprise information technology function and global engineering organization. He also drives the company's advanced technologies supporting the global megatrends of safe, green, and connected.

**Alyssa Panitch – Purdue University**
Panitch is the Leslie A. Geddes Professor of Biomedical Engineering at Purdue, where she led a team that discovered a healing material that can be injected directly into a wound site. She was previously associate professor of bioengineering at Arizona State University and has launched three successful startups.

**Joel Podolny – Apple**
Podolny is vice president of human resources and dean of Apple University, a program initiated by the company in 2008 to teach executives how to think and ultimately emulate the successful strategies of Steve Jobs. He was previously dean of the Yale School of Management and has been a faculty member at Harvard Business School and Stanford Graduate School of Business.

**Jerl J. Purcell III – Cummins**
Purcell is executive director at Cummins, Inc., where he led the development of the latest three diesel engine platforms, including the ISF2.8, ISF3.8, and most recently the QSM12, each of which is a clean sheet design and uses modular systems. He is a member of the NAE's Making Value for America: Foundational Study.

**Maria Scileppi – 72U (72 and Sunny)**
Scileppi leads 72U, a 72 and Sunny program designed to cultivate the next generation of leaders for the creative industry. She has served as art director at Y&R NY and director at the Chicago Portfolio School, and worked on a collaborative storytelling project, "Journey Home," based on shared experiences.

**Susan Sloan – National Research Council**
Sloan is director of the NRC Government-University-Industry Research Roundtable. She has also worked as the corporate/foundation relations consultant for the NSF's Division of Undergraduate Education and as associate director of the Master of Health Science in Health Policy program at Johns Hopkins University School of Public Health.

**Dwayne Spradlin – Health Data Consortium**
Spradlin is head of the Health Data Consortium, a major nonprofit private/public initiative supported by the Robert Wood Johnson Foundation, US Department of Health and Human Services, and others. He was previously president and CEO of InnoCentive, president of Hoovers Online, president and COO of StarCite Inc., senior vice president at VerticalNet Inc., and director at PriceWaterhouseCoopers.

**David Stone – University Laboratory High School, Champaign, IL**
Stone teaches biology at University Laboratory High School on the campus of the University of Illinois at Urbana-Champaign. He has been a collaborating educator on a number of projects and has worked with the National Center for Supercomputing Applications.

**Nina Tandon – Columbia University/EpiBone**
Tandon studies electrical signaling in the context of tissue engineering. She is an adjunct professor of electrical engineering at the Cooper Union and works as an electrical and biomedical engineer at Columbia University's Laboratory for Stem Cells and Tissue Engineering. She is cofounder and CEO of EpiBone, a company that uses scans of patients' bone defects and their own stem cells to engineer personalized bone grafts.

**Herbert Holden Thorp – Washington University in St. Louis**

Thorp is a chemist, entrepreneur, inventor, musician, and professor, and has cofounded multiple biotechnology startups. He is provost of Washington University in St. Louis and was previously chancellor of the University of North Carolina at Chapel Hill. He has cofounded multiple biotechnology startups, is an inaugural member of the National Advisory Council on Innovation and Entrepreneurship, and serves on the US Manufacturing Competitiveness Initiative for the Council on Competitiveness.

**Andy Walshe – Red Bull**

As Red Bull's High Performance Director, Walshe seeks to develop a greater understanding of the "human potential" construct and its application to the betterment of society. He specializes in human performance at the highest levels and the development of talent in a strategic framework to optimize the potential of individuals, teams, and organizations.

**Karan Watson – Texas A&M University**

Watson is Texas A&M University's provost and executive vice president for academic affairs. She was previously the school's vice provost, dean of faculties, and associate provost. She is Regents' Professor in the Department of Electrical and Computer Engineering and in the Department of Computer Science and Engineering.

**Harry West – Continuum Innovation**

West has been involved in design and innovation for over 25 years: on the faculty at MIT, as a design consultant at Continuum where he was CEO, and now as an independent consultant working for the World Bank on G2P payments for low-income women in Pakistan. Working with Procter & Gamble he helped create the Swiffer, and working with BBVA he helped create its customer-centric banking model.

**Katie Whitefoot – National Academy of Engineering**

Whitefoot is senior program officer for Manufacturing, Design, and Innovation at the National Academy of Engineering. She conceptualizes and manages studies on the condition of the US-based manufacturing value chain and implications for businesses, customers, and the nation's well-being.

# Appendix E
# Other Information Desired from the Interview Analysis

The workshop participants were asked what more they would like to learn from the interview analysis. The following notes may suggest directions for future research in this area and would inform the next phase of the project that focuses on understanding how to build environments for educating to innovate.

- What were the innovators' views on how to actually teach innovation?
- What about the licensing model? It doesn't create growth development or job creation.
- Have a forum to hear the long version of President Mote's talk.
- At what time in people's lives do they become innovators?
- What are very specific examples of experiences that made them innovators?
- What impeded their becoming an innovator? (It seems as though many became innovators in spite of their education.)
- Provide information about experiences when a teacher rewarded or appreciated their giving an answer or explanation that was different from what the teacher expected. Then look at the variety of their examples and infer what teachers do that models innovative thinking.
- Look at when people had experiences to play and explore without a pre-determined outcome. When did you hear that the process was valued, not just the outcome?
- How did people learn through their failures?
- Balance teaching the fundamentals with processing and manipulation time.
- For the categories (skills, experience, environments), how did each affect their process for innovating?
- Why did classmates fall to the wayside and they themselves bloomed?
- What cultures are the most fruitful for innovation, for learning to learn? What learning experiences had the most impact?
- Ask them to watch or listen to other innovators' interviews or transcripts. What two or three things, as you listen to the other innovator(s), ring true?

- Are there patterns in upbringing, parents, living arrangements, and the role of noncurricular activities in students' lives?
- Add "culture" as a category. A participant says she would not be as successful as an entrepreneur if she were working in another company environment; the specific culture is important, she says.
- What is the significance of individual actions and experiences as distinct from group experiences? How did each of these settings figure into different parts of their development?
- How did they break paradigms? How were they iconoclastic?
- How did they feel among their peers socially? Did they perceive themselves to be popular? Test the hypothesis that the really popular people may not be the iconoclasts, innovators, or future entrepreneurs.

# Appendix F
# Steering Committee Bios

**Arden Bement, Jr. (NAE),** ***Chair*** **– Purdue University**
Bement was director of the National Science Foundation from 2004 to 2010 and before that director of the National Institute of Standards and Technology. At Purdue University, he is the inaugural director (emeritus) of the Global Policy Research Institute and David A. Ross Distinguished Professor Emeritus of Nuclear Engineering. His 39-year career in industry, government, and academia includes service as vice president of technical resources and of science and technology for TRW Inc., deputy under secretary of defense for research and engineering, director of DARPA's Office of Materials Science, and professor of nuclear materials at MIT. A fellow of the American Academy of Arts and Sciences and American Association for the Advancement of Science, he has been awarded the Order of the Rising Sun from the Empire of Japan and Chevalier dans l'Ordre National de la Légion d'Honneur from the French Republic.

**John Seely Brown – Deloitte Center for the Edge/University of Southern California**
Brown is the independent cochair of the Deloitte Center for the Edge and a visiting scholar and advisor to the provost at USC. He holds seven honorary doctorates from various prestigious universities, was inducted into the Industry Hall of Fame, and was elected to the American Academy of Arts and Sciences. Part scientist, part artist, and part strategist, he sees himself as the "Chief of Confusion, helping people ask the right questions, trying to make a difference through [his] work—speaking, writing, and teaching." He was previously chief scientist of Xerox Corporation and director of its Palo Alto Research Center (PARC) for nearly two decades. He cofounded the Institute for Research on Learning (IRL) and is interested in digital youth culture, digital media, and institutional innovation. He is a member of the National Academy of Education, a fellow of the American Association for Artificial Intelligence and of AAAS, and a trustee of Brown University and the MacArthur Foundation. He also serves on numerous public boards (Amazon, Corning, Varian Medical Systems, and Polycom) and private boards of directors.

**Jared Cohon (NAE) – Carnegie Mellon University**

Cohon is president emeritus and university professor of civil and environmental engineering and engineering and public policy at Carnegie Mellon University (CMU). As president (1997–2013), he guided CMU's global expansion and led its efforts in diversity, technology, international education, and economic development in southwest Pennsylvania. He was previously dean of the School of Forestry and Environmental Studies at Yale University, and was on the faculty of Johns Hopkins University's Department of Geography and Environmental Engineering. President Clinton appointed him to the Nuclear Waste Technical Review Board in 1995 and appointed him chairman in 1997. In 2002 President George W. Bush appointed Cohon to the Homeland Security Advisory Council, and in 2009 he was reappointed by President Obama.

**Nicholas Donofrio (NAE) – IBM (ret.)**

Donofrio is an IBM Fellow and a 44-year IBM veteran who retired as IBM's Executive Vice President of Innovation and Technology. He was also vice chair of the IBM International Foundation and chair of the board of governors for the IBM Academy of Technology. Outside of IBM, he has been dedicated to education and career advancement for underrepresented minorities and women. He was board chair of the National Action Council for Minorities in Engineering (NACME) from 1997 through 2002, and was on the board of directors for INROADS, a nonprofit that trains and helps minority youth for careers in business and industry. In 2003 he was awarded the Rodney D. Chipps Memorial Award by the Society of Women Engineers (SWE). He cochairs the New York Hall of Science. He led the work of the Council on Competitiveness in its National Innovation Initiative (NII), which was the basis for the America Competes Act. In 2005 he was appointed to the Commission of the Future of Higher Education by the US Department of Education. He is a fellow of the IEEE, Royal Academy of Engineering, and American Academy of Arts and Sciences, and serves on the boards of directors for the Bank of New York/Mellon, Liberty Mutual, Delphi Automotive, AMD, and MITRE. He was a senior fellow at the Kauffman Foundation (2009–2012) and cochair of the Secretary of Energy's Advisory Board (2009–2012).

**James Duderstadt (NAE) – University of Michigan**

Duderstadt is president emeritus and university professor of science and engineering at the University of Michigan. He has served on or chaired numerous public and private boards, including the National Science Board and the National Commission on the Future of Higher Education. He currently serves on major national boards and study commissions on federal science policy, higher education, information technology, energy sciences, and national security, including the NSF Advisory Committee on Cyberinfrastructure, the Glion Colloquium in Switzerland, and the Intelligence Science Board. He has received numerous national awards for his research, teaching, and service, including the E.O. Lawrence Award for excellence in nuclear research, the Arthur Holly Compton Prize for outstanding teaching, the Reginald Wilson Award for national leadership in achieving diversity, and the National Medal of Technology for exemplary service to the nation.

**Krisztina "Z" Holly – City of Los Angeles Mayor's Office**

Holly serves as entrepreneur-in-residence for the City of Los Angeles Mayor's Office and chairs the World Economic Forum Global Agenda Council for fostering entrepreneurship. She was the creator and curator of the first TEDx event, vice provost for innovation at USC, and founding executive director of the MIT Deshpande Center, which helped spin out 39 startups based on university research and enhanced the entrepreneurial ecosystems of Boston and Los Angeles. Early on she was cofounder of computer telephony pioneer Stylus Innovation (acquired by Artisoft, Inc.) and subsequently joined other tech and media startups, including Direct Hit Technologies (acquired by Ask Jeeves). She has also worked in documentary film production and on engineering projects including the space shuttle main engine, a head-eye robot for the MIT artificial intelligence laboratory, and the first full-color computer-generated reflection hologram at the MIT Media Lab. Named Champion of Free Enterprise by Forbes in 2010, her work has appeared in the *Economist*, *BusinessWeek*, *strategy+business*, *Huffington Post*, CNN.com, Big Think, Science Progress, NASA Ask, and *Mountain Bike Magazine*. She has been active in board and advisory roles, including the US National Advisory Council for Innovation and Entrepreneurship.

**C. D. Mote, Jr. (NAE) – National Academy of Engineering**

Mote served on the steering committee until he began his term as president of the National Academy of Engineering on July 1, 2013. He is also a Regents' Professor on leave from the University of Maryland, College Park. He cochaired the Committee on Science, Technology, Engineering, and Mathematics Workforce Needs for the US Department of Defense and the US Industrial Base and was a member of the NRC committee that authored the *Rising Above the Gathering Storm* reports of 2005 and 2010. He has received the NAE Founders Award, the American Society of Mechanical Engineers Medal, and the Humboldt Prize of the Federal Republic of Germany. At the University of California, Berkeley, he was honored with the Distinguished Teaching Award and Excellence in Achievement Award. He is an honorary fellow of the American Society of Mechanical Engineers and fellow of the American Academy of Arts and Sciences, American Academy of Mechanics, Acoustical Society of America, and American Association for the Advancement of Science.

**Gail Naughton – Histogen, Inc.**

Naughton is the founder (in 2007), chair, and chief executive officer of Histogen, Inc. Before that she was vice chair, president, chief operating officer, and cofounder and director (since its inception in 1991) of Advanced Tissue Sciences, Inc. (ATS) (human-based tissue engineering). She is on the board of multiple committees of C.R. Bard, Inc., has conducted extensive research and authored numerous scientific publications, and holds more than 95 US and foreign patents. She also has a distinguished academic career, having served as dean of the San Diego State University College of Business Administration and on the boards of several academic institutions, nonprofit organizations, and foundations. Naughton was the first woman to receive the National Inventor of the Year award (in 2000) from the Intellectual Property Owners Association.

**Lydia Villa-Komaroff – Cytonome**

Villa-Komaroff, chief scientific officer at Cytonome, has had a 20-year research career spanning positions at MIT, Harvard University, University of Massachusetts Medical School, and Harvard Medical School. She also previously served as vice president for research at Northwestern University, and vice president for research and chief operating officer of Whitehead Institute for Biomedical Research. She was elected to the AAAS board of directors and chaired the board of directors of Transkaryotic Therapies. A pioneer in the field of cloning, she has overcome both racial and gender inequality in higher education, eventually becoming the third Mexican American woman in the United States to receive a doctorate in the sciences. In addition to several honorary degrees, Villa-Komaroff has received the Hispanic Engineer National Achievement Award (1992) and the Women Entrepreneurs in Science & Technology (WEST) leadership award (2001), and in 2008 she was named National Hispanic Scientist of the Year by the Museum of Science and Industry.

# Appendix G
# Project Team Bios

**Kimber Jo Andrews – University of Illinois at Urbana-Champaign**
Andrews considers herself a jack of all trades, having worked as a professional dancer, choreographer, multimedia performance artist, videographer, curriculum designer, and educator. She is currently a PhD student at the University of Illinois at Urbana-Champaign in the College of Education with a focus on aesthetics and qualitative research methodology.

**Laura Atkins – University of Illinois at Urbana-Champaign**
Atkins is a fourth-year doctoral student in the UIUC Department of Sociology. Her research interests relate to health disparities along class, gender, and racial lines, and her dissertation is a qualitative study of the psychosocial effects caused by toxic contamination in disease cluster communities. She has experience leading workshops on qualitative and quantitative software programs, developing survey instruments, interviewing and conducting focus groups, and, as an ATLAS research consultant, she assists with qualitative coding and analysis of innovator transcripts in ATLAS.ti™.

**Liora Bresler – University of Illinois at Urbana-Champaign**
Bresler is a professor at the College of Education, College of Fine and Applied Arts (School of Art and Design and School of Music), and fellow in the Academy of Entrepreneurial Leadership at the University of Illinois at Urbana-Champaign. She is a distinguished fellow of the National Art Education Association, and has received numerous awards and honors for her education leadership and teaching efforts. She cofounded the *International Journal for Arts and Education*, serves as an editor for the book series Landscapes: Aesthetics, Arts, and Education, and has written over 100 chapters in leading education and arts journals. She has given keynote speeches on six continents and invited talks, seminars, and short courses in 30-some countries.

**Debasish (Deba) Dutta – Purdue University**
Dutta is a scholar in residence at the National Academy of Engineering and director of the Educate to Innovate project. He is executive vice president for academic affairs and provost of Purdue University. Previously, he was associate provost and dean of the Graduate College at the University of Illinois at Urbana-Champaign, where he was also Edward William and Jane Marr Gutgsell Professor in the Department of Mechanical Science and Engineering. He directed the Lifelong Learning Imperative project at the NAE. Before joining Illinois in 2009, he was on the engineering faculty at the University of Michigan for 20 years. At NSF, he has served as acting director of the Division of Graduate Education, IGERT Program Director, and advisor in the Office of Assistant Director, Education and Human Resources. He helped develop the NSF's Cyberinfrastructure Strategy and chaired its Learning and Workforce Development subcommittee.

**Cameron H. Fletcher – National Academy of Engineering**
Fletcher is senior editor of the National Academy of Engineering and managing editor of NAE's quarterly journal, the *Bridge*.

**Penelope Gibbs – National Academy of Engineering**
Gibbs is a senior program associate in the NAE Program Office. She supports the office director, the senior program officer for Manufacturing, Design, and Innovation, and the senior editor.

**Barbara Hug – University of Illinois at Urbana-Champaign**
Hug is a clinical associate professor with the Department of Curriculum and Instruction at UIUC. She is interested in developing and using curriculum materials that support inquiry learning in science and understanding the inquiry practices of students as they engage in extended investigations. Her current research investigates the supports needed by both teachers and students as they engage in science inquiry practices. Accordingly, her current work involves collaboration with a wide array of individuals from various backgrounds and includes examining both professional development and classroom environments.

**Julian Martinez-Moreno – University of Illinois at Urbana-Champaign**
A recent graduate of UIUC, Martinez-Moreno holds a BS in psychology and a BA in sociology. He began working at Applied Technologies for Learning in the Arts and Sciences (ATLAS) as an intern and his role has extended to that of survey research assistant, most often working with qualitative data analysis and coding. He hopes to pursue a PhD in sociology as well as a JD, as his research interests concern the efficacy and public perception of the American criminal justice system.

**Lalit Patil – University of Illinois at Urbana-Champaign**
Patil is the principal researcher on the Educate to Innovate project and was also principal researcher on the Lifelong Learning Imperative project. He is a postdoctoral research fellow with the Department of Mechanical Science and Engineering at UIUC and man-

ages research at the Product Lifecycle Management lab. His research in mechanical engineering focuses on the role of information and semantics in managing and improving product design and manufacturing. He has also worked as a senior research fellow and senior lecturer at the University of Michigan.

**Proctor Reid – National Academy of Engineering**
As director of the NAE's Program Office, Reid oversees all NAE program activities and staff and directs the NAE policy research programs on engineering, the economy, and society; engineering and health care; and engineering, energy, and the environment. He has served as secretary to the AAAS Section on Industrial Science and Technology and worked as a consultant to the Organization for Economic Cooperation and Development. He received his PhD in international relations from the Johns Hopkins University Paul Nitze School of Advanced International Studies.

**Kathleen Santa Ana – University of Illinois at Urbana-Champaign**
Santa Ana holds a BA in economics from UIUC and is a survey research assistant with the Applied Technologies for Learning in the Arts and Sciences (ATLAS) statistics/GIS consulting unit, meaning she focuses on the data side of survey research. She regularly cleans and codes for data analysis and collaborates with researchers to design surveys that provide reliable data to address their research questions. Santa Ana works mostly with SPSS, but she is also interested in Python, LaTeX, and, more specifically, the amalgamation of the three in streamlining data cleaning and reporting.

**Maryalice Wu – University of Illinois at Urbana-Champaign**
Wu is director of Applied Technologies for Learning in the Arts and Sciences (ATLAS), supervisor of the Statistics, GIS, Data, and Survey research group, and an adjunct assistant professor in the Department of Sociology at the University of Illinois at Urbana-Champaign. She was the primary investigator on broadband penetration in the Champaign-Urbana area, resulting in a $23.5 million federal grant for fiber-to-home installation. Her recent research focuses on the economic and health empowerment of women in developing nations. Her other projects relate to program evaluations in academia, including research on the impact of MOOCs (massive open online courses).