GRACE J. WANG

# Revisiting the Connection Between Innovation, Education, and Regional Economic Growth

What have we learned over the past 40 years about how to generate sustained economic growth through scientific research and technological innovation?

Forty years ago, Bruce Babbitt, then governor of Arizona, wrote in the first issue of this magazine that state and local governments had "discovered scientific research and technological innovation as the prime force for economic growth and job creation." The last four decades have tested the soundness of this claim. Though advancements in research and technology have undoubtedly transformed regional and national economies, technological innovation alone has not been an economic silver bullet. In fact, the impacts of innovation have been far more broad—disruptive technologies have driven industry shifts, transformed the nature of work, connected partners across the globe, and affected many aspects of society in ways that were likely unthinkable in 1984.

Although some regions managed to harness innovation as an economic force, many places across the United States still struggle to assemble the components necessary to realize sustained economic growth. We now know that regional growth requires a deliberate blend of ideas, talent, placemaking, partnerships, and investment. First, it calls for dynamic research and development capacity, usually provided by research universities or federal, nonprofit, or industry research labs, to continuously foster discovery and development of new knowledge and concepts. Second, a large and diverse talent pool with expertise and experience relevant to the industrial sectors in the region is paramount. Third, a physical place or an innovation hub is needed to foster dynamic interactions and collaborations among academic researchers, industry partners, entrepreneurs, and community leaders. Fourth, financial and policy support from state and local governments is critical to direct resources and remove barriers. Finally, a growing regional economy often has robust venture capital capacity and a healthy entrepreneurial ecosystem.

Governor Babbitt used gardening metaphors to talk about technology's impact over time: "rooting," "blooming," "ripening," and "harvesting." In hindsight, those metaphors leave out the collective, intentional, and coordinated work that must be done to make regional change happen, not only for jobs, but across society. The term I would use is "nucleating," which refers to creating a central ecosystem that can support continual outward growth. Nucleation requires persistence and intent, and its effects can be far-reaching.

Excerpts from Bruce Babbitt, "The States and the Reindustrialization of America," *Issues in Science and Technology* 1, no. 1 (Fall 1984): 84–93.

Two years ago ten American high technology companies, including Control Data, Honeywell, Lockheed, Motorola, Sperry, and NCR, stepped forward to meet the Japanese challenge for supremacy in supercomputer development by pooling resources to form a research consortium called Microelectronics and Computers Corporation (MCC). The consortium hired a former deputy head of the Central Intelligence Agency, Admiral Bobby Inman, to run MCC, and the admiral set out to find a permanent home for his new company.

Admiral Inman and his associates toured the country like an imperial court as mayors and governors extolled the virtues of their respective sites and offered up such tangible inducements as real estate, research facilities, and endowed professorships. When the bidding finally peaked with an unbeatable offer from Texas, Inman had secured a multimillion dollar package, including thirty million dollars in faculty endowments at the University of Texas in Austin, thirty-seven million dollars in equipment and operating expenses, twenty acres of land at nominal rent in the Balcomes Research Park, twenty million dollars worth of office space, subsidized home mortgages for MCC employees, a petty cash fund of a half-million dollars for country club initiation fees and other services, and a Lear jet with two pilots available at all times. Some sixty mayors and twenty-seven governors complained about the unfair advantage of Texas oil money and promised their constituents a better showing next time.

The great MCC bidding war marks a special chapter in American industrial history. State and local governments across the country have discovered scientific research and technological innovation as the prime force for economic growth and job creation. And local officials have also uncovered a broad base of public interest that can be translated into support for aggressive action programs. With the exception, perhaps, of the post-Sputnik era, such grassroots enthusiasm for science and technology has not been seen since the Gilded Age of the nineteenth century, when communities vied to finance the transcontinental railroads.

## Economic value of academic research

For much of the 1980s, translating research findings and breakthroughs from universities and government labs into commercially viable products or services was seen as the key to gaining a competitive advantage in the global economy. At the time, Babbitt observed increasing levels of investment in university research and development, coupled with a recognition that "the fruits of university research and development activity have little economic value unless they are systematically harvested in the marketplace."

Then and now, one would argue that not all academic research should be motivated by economic potential, though many academic research efforts contribute to solutions that have economic value. Following the passage of the Bayh-Dole Act of 1980, many research universities installed technology transfer offices to harvest the economic value of inventions resulting from academic research funded by the federal government and other sponsors. Over the last few decades, these offices have played a significant role in bringing the concept of technology commercialization to university campuses, and have established best practices and policies in patent management and licensing agreements.

However, most university technology transfer offices cannot break even financially. A 2013 Brookings Institution report on university startups estimated that from 1992 to 2012, on average, 87% of technology transfer offices did not generate enough licensing income to cover the wages of their technology transfer staff and the legal costs filing patents. Today, many technology transfer offices face greater pressure to generate more licensing income, which requires balancing necessarily robust patent portfolios with the cost of maintaining such operations.

From invention disclosures and patent applications to licensing, follow-on R&D investment, and sometimes clinical trials and regulatory approval, it generally takes years for a new technology to reach the marketplace. The process is more frequently iterative than linear, requiring deep engagement and collaboration between academic inventors and the industry or startup licensees. To facilitate this untidy process successfully, universities must connect technology transfer offices with corporate partnerships and entrepreneurial activities on campus, which can be organizationally challenging. A number of other pitfalls may prevent academic inventions from realizing their full economic potential, including lacking a place for technology incubation, insufficient funding to bridge the "valley of death," and inadequate understanding of market need or addressable market size for the product. For these reasons, technology commercialization takes integrated efforts and partnerships—it is an ongoing process of investing in the future.

Over the last 50 years, many federal initiatives have been created to foster long-term partnerships and investment to address critical challenges within the research ecosystem. For instance, in 1973, the National Science Foundation (NSF) launched the Industry-University Cooperative Research Centers program to develop long-term partnerships among industry, academia, and government.

> Nearly every state has increased its support for university-based research and development.

> What is noteworthy is that behind this funding lies a new awareness that the fruits of university research and development activity have little economic value unless they are systematically harvested in the marketplace. Every

> research into marketable products. Many state technology programs have recognized the traditional wall that separates the university from the business community as a barrier to innovation and business development; steps are being taken to eliminate the barriers and to build bridges of cooperation.

In 1985, NSF established the Engineering Research Center (ERC) program. Each center is designed as a 10-year endeavor, and the program has become a successful platform for faculty, students, and staff in academia to collaborate with industry while working on complex long-term challenges; producing new knowledge, technologies, and startups; and preparing talent for emerging technological sectors.

In 2007, the National Academies of Sciences, Engineering, and Medicine released a congressionally mandated report, *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future*. The report recommended federal policymakers take actions to enhance the science and technology research enterprise with the goals of creating high-quality jobs and meeting the nation's needs in clean, affordable energy. That same year, the America COMPETES Act was signed into law, which officially authorized the creation of the Advanced Research Projects Agency-Energy (ARPA-E). The ARPA model stresses the importance of agile but potentially transformative investments in project-based, high-risk research and technology development. Though the arc of an ARPA project may be just a few years, the existence of an agency—or multiple agencies—to coordinate such investments is itself a long-term, future-oriented effort.

In 2014, the Revitalize American Manufacturing and Innovation Act authorized the Department of Commerce to initiate the National Network for Manufacturing Innovation, now known as Manufacturing USA, to secure US leadership in advanced manufacturing. Today, Manufacturing USA is a national network of 17 linked regional manufacturing institutes, where academic, industry, and other stakeholders collaboratively develop new technologies, test prototypes, and enable the future manufacturing workforce.

Efforts to capitalize on university research continue. The CHIPS and Science Act of 2022 created NSF's Regional Innovation Engines and the Economic Development Administration's Regional Technology and Innovation Hubs programs. These programs are new commitments to the enduring idea that long-term investment that focuses on critical challenges is needed to nucleate and expand innovation ecosystems. In this sense, Babbitt's initial insight about the centrality of research and technological innovation to regional economic health stands the test of time and has become more significant, albeit in a far more complex form.

## Evolution of place-based innovation

Beyond the efforts of federal initiatives and universities, the goal of nucleating and growing innovation ecosystems has sparked new models of place-based innovation at regional and state levels over the past several decades. State and local governments as well as regional business communities played significant roles in the establishment of these place-based innovation ecosystems, which continue to shape the landscape of innovation. It is important to note that the role of state and local government is neither passive nor confined to a single valence such as zoning or tax incentives.

The first university research park—now a widely adopted model in the United States and worldwide—was formed in the 1950s. City and university leaders partnered to allow Palo Alto, California, to annex land from Stanford University for R&D industrial development. The dynamic mix and high concentration of companies that formed across Stanford Research Park became one of the driving forces behind the development of Silicon Valley. Although Stanford Research Park is only two miles away from the university campus, these companies technically do not co-locate with university researchers.

Another well-known research park is North Carolina's Research Triangle Park. Leveraging the capacity of three nearby research universities—the University of North Carolina at Chapel Hill, North Carolina State, and Duke University—Research Triangle Park was established in the late 1950s with strong support from the state, cities, local business leaders, and universities. Today, numerous businesses and employees call Research Triangle Park home, and its high density of companies and talent helps attract research-driven organizations and people, fueling regional economic growth.

> To be effective, a research park must have more than a prestigious location with the word "university" in its address. Success relies on a solid linkage between industry and university personnel working on shared research, a carefully thought-out university patent policy that encourages entrepreneurship, and a supportive university administration. The availability of venture capital and professional management skills is also important. Most universities have little notion of the potential commercial successes languishing in their research laboratories.

In recent decades, a new model has been emerging: the co-location of university research and education facilities, industry partners, startup companies, retail, maker spaces, and even apartments, hotels, and fitness centers. This "innovation district" model features a high density of companies and talent; open and highly connected placemaking; and culturally dynamic living, working, and social environment that enables ideation and collaboration. Researchers, industry partners, entrepreneurs, and investors work and socialize in these innovation districts, bouncing ideas, forming partnerships, and starting new ventures.

Kendall Square in Cambridge, Massachusetts, is a well-known example of an innovation district. Kendall Square was originally known as an industrial district, but since the 1990s, a concentration of offices and lab spaces for large corporations, startups, incubators, and apartments, hotels, restaurants, and retail have developed. The dynamism of the square mile comprising the district, in walking distance to the Massachusetts Institute of Technology, provides an intellectually stimulating and socially interactive environment that catalyzes partnerships and attracts more co-locating businesses and organizations.

Innovation districts do not just happen spontaneously; they require tremendous attention to placemaking. Details such as the design of lab and office space, connectivity between buildings, location of open space, position of parking garages, and the density of restaurants and coffee shops can all influence its overall environment.

Today, regional innovation ecosystems have become globally networked as well as regionally clustered and place-based. Thanks to the widespread adoption of virtual meeting platforms, researchers, business leaders, and entrepreneurs can now connect across the globe. But research, innovation, and technology development often call for deeper collaboration and in-person interactions; therefore, it is unlikely that virtual platforms will replace placed-based innovation. Instead, they will complement each other, making regional ecosystems even more effective.

This new trend in connectivity may also enable more distributed economic growth. In the last few decades, research-driven economic growth has occurred mainly along the coasts or in major metropolitan areas. Virtual networks may now be helpful in nucleating growth in regions that have struggled economically, for example, by bringing funding to regions that currently lack a venture capital or angel investment community.

Inspired by new patterns of public and private cooperation and approaches to stimulate education reform, Babbitt said it was still "too early to pick the fruit." A lesson from the last 40 years is that successful efforts take deliberate actions. Regions that can master the art of cultivating partnerships and nucleating place-based innovation will be well positioned for the future.

## Propagating entrepreneurial ecosystems

Technology-based startups are a key component of an innovation economy. They hold high potential for generating financial returns, but more importantly, they enable new jobs, business models, and even industry sectors. They drive the dynamics of a regional ecosystem, stimulate excitement and creativity, and attract talent and investors who share their motives and passion.

But technology-based startups also face unique risks associated with technology development: a frequently long runway to commercialization, sizable capital investment, uncertain team dynamics, and emerging and ever-changing markets.

These combined risks are often referred to as the valley of death. Since the 1980s, many programs have attempted to bridge the valley of death by "de-risking" technology-based startups. For example, in 1982, through the Small Business Innovation Development Act, the Small Business Innovation Research, or SBIR, program was created to stimulate technological innovation and support small businesses. In 1998, Maryland established the Maryland

Technology Development Corporation to facilitate the creation of early-stage companies, provide funding, and support their growth. And around 2000, Kentucky stood up the Kentucky Enterprise Fund, providing pre-seed and seed-stage venture capital-type investments to high-growth startups. In 2011, the NSF launched the Innovation Corps (I-Corps) program, providing experiential learning of market discovery for entrepreneurial teams to evaluate the market need and potential of their inventions.

This constellation of federal and state investments in pre-seed or seed-stage startups has been effective but not sufficient. Substantial follow-on private investment is frequently needed for technology-based startups to develop a market-viable product or service, build business partnerships, establish manufacturing or distribution channels or both, and ramp up revenue streams. Venture capital funds and angel investment networks are essential for the growth of a regional entrepreneurial ecosystem.

However, US venture capital funding is highly concentrated in a few metropolitan areas. According to CB Insights, US venture funding reached a total of $198 billion in 2022, of which about $128 billion was invested in the Silicon Valley, New York, Los Angeles, and Boston areas.

Only concerted efforts among state government, research universities, philanthropy, and local startup incubators can build the resources to host and retain startups in a region, provide seed funding, and cultivate a compelling, high-quality deal pipeline, which will in turn attract more capital investment to regions.

## STEM education and talent for new challenges

Babbitt observed the increasing sophistication of science, technology, engineering, and mathematics—STEM—careers and called for education reforms that could prepare a new workforce to brave the coming "information revolution." But even this insight fell short of understanding the many ways the acceleration of innovation would affect jobs, the economy, and communities.

STEM employment has grown considerably and since the 1980s, technology has transformed health care, banking, insurance, legal services, manufacturing, agriculture, transportation, and retail. Today, STEM jobs are found across almost all business sectors. For instance, the use of predictive analytics to establish customers' purchasing patterns to manage supply chains has created demand for STEM jobs in the retail industry. In fact, from 1990 to 2016, STEM employment has grown by 79%, while overall employment grew by only 34%. With generative artificial intelligence, the future of STEM jobs remains in flux—a 2023 McKinsey report predicted that an additional 12 million US workers may need to transition to different occupations by 2030.

Today's societal challenges need more than traditional STEM education. Pressing needs for innovation in energy, water, food, land use, environmental sustainability, health care, and education require solutions that stretch beyond science, engineering, and technology. To be prepared, today's STEM students need to learn the most advanced knowledge in their fields, in addition to understanding business and policy principles and being able to discern different cultural, societal, and historical contexts. They need to be collaborative team players, creative and critical thinkers, motivated value creators, and effective communicators.

Traditional classroom learning is no longer sufficient to prepare the next generations of STEM workers and leaders. To keep pace, STEM education must provide both foundational knowledge and hands-on experience and skills. For decades, universities have experimented with modalities of experiential learning, ranging from internships, co-ops, on-campus capstone projects, and off-campus project-based learning. These are no longer optional, but required.

Worcester Polytechnic Institute (WPI), where I am now president, has been providing project-based learning since the 1970s. Today, WPI students form interdisciplinary teams and immerse themselves in real-world settings, working in one of WPI's global project centers to solve problems full time for a period of seven weeks. This transformative

> The relationship between economic change and education can be dramatized by comparing a couple of help-wanted ads. The following ad was run in a San Francisco newspaper in 1860 by the organizers of the Pony Express: "WANTED: Young, skinny, wiry fellows, not over 18. Must be expert riders willing to risk death daily. Orphans preferred."
>
> The following ad for engineers appeared in a recent edition of *The Los Angeles Times*: "Your background should include extensive experience with repetitively-pulsed excimer lasers, with emphasis on pulsed power, fluid dynamics, and materials science aspects. An additional background in linear and nonlinear optics, electronics, and computer modeling would be helpful."
>
> In 1860 most of those wiry young orphans couldn't read or write, which made little difference because literacy never has been a requirement for riding a horse. Many of today's new careers are far more sophisticated.

> The best new approaches to reinvigorate scientific research, to build new patterns of public and private cooperation, stimulate educational reform, and promote savings and capital investment are beginning to bloom somewhere out in the American heartland. It is still a little early to pick the fruit, but we can be confident that harvest time is not too far away.

learning experience prepares students to work as a team, learn how to learn, communicate and collaborate, see the world from different cultural perspectives, and most importantly, be motivated to address problems that truly matter to society. As a result, WPI graduates are sought out by employers. They are not only knowledge- and job-ready, but also career-ready.

But reimagining STEM education must also happen beyond college-level preparation. It is widely known that academic interest in STEM is developed in early childhood and middle school. However, there are still many K–12 schools across the country without sufficient access to STEM curricula or extracurricular activities. While this issue is complex and requires persistent effort and sustained investment, one challenge policymakers must face head-on is the K–12 teacher shortage. Babbitt mentioned teacher shortages in science and mathematics in the 1980s. The problem has not budged. A 2023 Learning Policy Institute report estimated that about 1 in 10 of all teaching positions nationally were either unfilled or filled by teachers not fully certified for their assignments. The long-term impact of K–12 teacher shortages is significant and may play a role in undoing other efforts to catalyze economic growth.

Cultivating a large K–12 STEM talent pool calls for collaborative and innovative approaches to nurturing curiosity and inspiring deep, lasting interest among learners of all ages. To complement classroom learning, nonprofit organizations such as museums, competitions, networks, and clubs can offer interactive and motivating experiences where this kind of inspiration is often sparked. For instance, For Inspiration and Recognition of Science and Technology, or FIRST, the community behind the youth-serving robotics competition founded in 1989, provides engaging robotics activities that have opened horizons for generations of students to access the power of knowledge, creativity, and teamworking.

Numerous STEM outreach programs have been established over the last few decades. To benefit more students and deliver lasting impact, these programs need to achieve not only learning outcomes, but also scalability and affordability.

## The importance of considering societal impact

The world Babbitt was writing from in 1984 looks markedly different from today: we are now exponentially more connected, we generate and depend on vastly more data, and technology has made many aspects of life and work more convenient and efficient. On the other hand, some technologies have created unintended sociological, societal, and environmental problems. It is useful to contemplate what the differences between the two eras might tell us about the future as we consider many of these challenges, still looking for answers to many of the same questions while facing another dramatic industrial shift.

From his perch, Babbitt saw technological innovation driving economic development at regional and state levels to form a nationwide trend. These shifts were related to the emergence of personal computers and the internet, which transformed business sectors and ultimately enabled new technologies and jobs in the following decades. What Babbitt couldn't foresee were the ripple effects of changes made to the regional, national, and global economy landscapes, as well as to our daily lives.

Today, we can imagine an analogous multidecade shift as generative and applied artificial intelligence, robotics, and life science breakthroughs—along with the vast data facilitated by ubiquitously connected devices—enable new technologies, businesses, and types of jobs. We must try to anticipate how such cascading changes will impact people's lives, society, culture, policy, and the planet.

More than ever, societal impact must be integrated with technological advancements, STEM education, and economic growth. It cannot be an afterthought; building a healthier, more bountiful, vibrant, and resilient society must be the guiding vision, as well as the goal, of a regional innovation ecosystem.

***Grace J. Wang*** *is the seventeenth president of Worcester Polytechnic Institute, where she is also a professor in the Department of Mechanical and Materials Engineering.*