2014 Association of American Physicians Presidential Address

Disruptive innovation as a driver of science and medicine

J. Larry Jameson

Academic medicine is an ecosystem. Like any ecosystem, critical factors affecting sustainability include diversity, disruptive external forces, and natural selection. Perhaps the most important issue we must grapple with is the extent to which we can proactively shape the future of academic medicine versus being subject to the natural forces of change. In thinking about this question, I am reminded of a quote from Ludwig van Beethoven in response to circumstances beyond his control. Faced with impending deafness, Beethoven said, "I shall seize fate by the throat; it shall certainly not bend and crush me completely" (1). Like Beethoven, the leaders in academic medicine should not only be resilient, but we have an obligation to society to identify creative solutions so that we can fulfill the AAP mission, as stated by Sir William Osler in 1885, "to advance scientific and practical medicine" (2). Never before have we had such advanced tools and the fund of knowledge to solve the ills of society. Indeed, Osler would be stunned to see the resources available to us.

Today, I want to address the role of disruptive innovation in science and medicine. In doing so, I will provide examples of disruptive innovation that has had lasting impact on society, attempt to predict where future disruption may occur, and suggest how we may play a more active role in shaping our future. Some of what I say, you would expect to hear from a physician-scientist and President of the AAP; some of my message, I hope, will surprise you.

Long before Clayton Christensen, a Professor at the Harvard Business School, coined the term "disruptive innovation," I experienced the compelling forces that underpin this idea (3). When I was an undergraduate student, a biochemistry professor introduced me to the concept of "affinity chromatography," a means to purify proteins by using their substrates or ligands to bind them to columns during chromatography (4). The yields were remarkable — it was a technology that I found elegant in its design, logic, and simplicity. Inspired by this technique, I joined the research group of Pedro Cuatrecasas, one of the pioneers of affinity chromatography. My subsequent PhD work occurred in the late 1970s and involved protein biochemistry and enzymology, work that I loved even though half my life was spent in the cold room. Near the end of my PhD work, a journal club presentation exposed me to something even more exciting — the expression of recombinant somatostatin in bacteria (5). I had an eerie feeling that the traditional biochemistry skills I had learned were about to be eclipsed. Contemplating how this new finding may impact future research, a chance encounter during my third-year clerkship with the pediatric endocrinologist Jud Van Wyk opened up a new path. At the time, Jud was concerned about the shortages of human growth hormone (hGH), the only treatment for children with growth-hormone deficiency. Human cadaveric pituitaries had been found to transmit Creutzfeldt-Jakob disease, ultimately leading to a ban on hGH (6, 7). I told him about the experiment to produce recombinant somatostatin and suggested that it might be possible to produce hGH using this approach. Jud charged me to learn recombinant DNA technology as a means to participate in this biologic revolution. With a little homework, I learned that endocrinologists at the Massachusetts General Hospital were collaborating with groups at MIT to introduce recombinant DNA technology into the field of endocrinology. I was fortunate enough to join them and immediately embraced this exciting field. The production of hGH using recombinant technology was ultimately accomplished in about 1980, circumventing our reliance on human tissue (8). This experience with the impact of recombinant DNA technology was a second example of a transformative disruptive technology in my young career. However, chance encounters may not always create opportunities. Thus, we must be proactive in structuring ecosystems that cultivate innovation and allow us to recognize these paradigm shifts and harness them to solve problems.

History is replete with examples of disruptive innovation, dating back to ancient times. Examples include the compass, the printing press, currency, gunpowder, and many others (9). As noted above, Clayton Christensen has more formally developed the concept of disruptive innovation as a major force of change in business, education, and health care. The general concept is that companies or industries face what has been termed the "innovator's dilemma" in that they are conflicted in response to a potential game-changing disruptive technology (3). This dilemma occurs because newer, and often cheaper, technologies threaten more profitable, sustaining innovations, making it difficult to substitute the newer technologies for the products that are generating the margins of today. These ideas are developed in his book, *The Innovator's Dilemma*, and subsequent books and articles, including, "Will disruptive innovations cure health care?" (3, 10). Imagine that you are Kodak, a company based largely on film, and someone develops digital imaging, or that you are a mainframe computer company like IBM or DEC, and advances in processors lead to the development of inexpensive but powerful personal computers. In our own lives, we recognize how cable or satellite TV has displaced air antennas and how cell phones have displaced landlines. E-mail, the successor to conversations, is now threatened by texting. News has moved from print to tablet to Twitter.

These types of disruptive innovations focus largely on technology. However, other powerful disruptive forces might also be

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Table 1
Ten examples of past disruptive forces in science and medicine

	Disruptive innovation	Category	Precursor state	Impact
1.	Plasmid cloning	Science	Protein purification Biochemistry	Recombinant DNA technology, biotechnology
2.	Macintosh computer	Technology	Word processing	Graphic interface
3.	Angioplasty and stents	Clinical	Coronary artery bypass graft Premature death	Acute cardiac intervention Salvage myocardium
4.	High-throughput DNA sequencing	Science	Gel-based sequencing	Human Genome Project; technology spinoffs
5.	Electronic publishing	Informatics	Paper journals Slow dissemination	Rapid dissemination Open access
6.	Institute of Medicine reports on quality and safety	Quality Variation in care	Autonomy Pay for performance	Improved quality
7.	Fiberoptics and robotics	Clinical	Open procedures	Minimally invasive surgery Reduced length of stay
8.	Smoking bans	Policy	Widespread smoking Secondary exposure	Reduced smoking Decreased disease
9.	3D imaging	Technology	X-rays	CT, MRI, PET Noninvasive diagnostics
10.	Targeted mutagenesis in mice	Science	Pharmacologic pathway inhibition	Gene function Identification of pathways

characterized as innovation. Many of these relate to social changes, often catalyzed by legislation. Examples include the Civil Rights Act, which expanded the rights of groups subject to discrimination but also reshaped education and the workforce (11). The Bayh-Dole Act granted potential ownership rights to inventions supported by federal funding, spurring the development of the biotechnology industry (12). Thus, disruptive forces can include technological advances as well as social or policy forces. For these forces to take root, one needs an environment that is receptive and adaptive.

It should be emphasized that disruptive forces should not be assumed to be "good" or "bad." Most have mixed features. For example, technological advances such as electronic health records provide ready access to data but also shift attention from the patient to the computer screen. Similarly, cardiac ultrasound provides remarkable diagnostic capability for heart disease, but many physicians rightly mourn the fact that it diminishes reliance on bedside diagnosis with a stethoscope, a symbolic and real link between doctor and patient.

The question I pose for academic medicine is the following: Is disruptive innovation analogous to evolutionary selection pressure with "survival of the fittest" and the extinction of those not adapted to the new environment? Or, if we accept that the innovator's dilemma is pervasive, can we use adaptive strategies that allow adoption of new technologies or approaches without risking survival? A few proactive, adaptive models have been proposed. One strategy is to develop smaller business units within the corporate structure to incubate innovation. This is analogous to population diversity as a hedge against evolutionary pressures. A second strategy is to define the mission differently such that generating a short-term benefit is not the primary goal of the organization. Arguably, Steve Jobs brought this strategy and philosophy to Apple. Namely, the primary goal was to innovate continuously, bridging art and technology, to produce products that people did not even know they wanted. If successful, profit margins will follow. Clearly, this is a challenging philosophy for businesses, and one that has challenged even Apple without its visionary leader at the helm.

Do these business concepts apply to academic medical centers (AMCs)? I contend that they do. We exhibit many of the characteristics of organizations at risk for resisting new, disruptive forces. We are, in fact, a profession and a guild with many inherent forces that resist change. In addition to tenure, licensure, and certification, our culture rarely adapts nimbly to opportunities for self-improvement. The Flexner report was required to integrate science into medical education (13). The Institute of Medicine reports "To err is human" and "Crossing the quality chasm" held a mirror to a health care system that was far too complacent about ensuring patient safety (14, 15). Electronic medical records could have been implemented a decade sooner if our profession was more accepting of strategies to re-engineer work flow, commit necessary capital investments in technology and people, and prioritize information management. We still resist team science because it can undermine personal advancement, even if collaborative science speeds discovery. This resistance occurs to varying degrees at the level of universities and funding agencies as well as with individual faculty. Finally, I believe our financial model shares many attributes of large, lumbering corporations. In fact, because of the regulatory environment and our complex reimbursement system, we may be even more resistant to change and innovation. As one example, it is challenging to develop innovative strategies to prevent hospital readmissions when (a) the hospital is reimbursed for the readmission and (b)

Table 2
Ten examples of current and future disruptive forces in science and medicine

	Disruptive innovation	Category	Precursor state	Potential impact
1.	Microbiome	Translational	Limited knowledge of flora	Manipulate immune and metabolic responses
2.	Stem cell isolation iPS cells	Translational	Descriptive developmental biology	Engineered cells Artificial organs
3.	Interdisciplinary programs	Diversity	Specialty silos	Novel boundary-spanning research and clinical programs
4.	Home monitoring devices	Technology	Physician visits	Monitor health 24/7
5.	Personalized diagnostics	Translational	Histopathology	Targeted cancer treatment Circulating cell detection
6.	Brain mapping	Neuroscience	Phenotypic classification	Genetic and neural pathway classification of neurological and psychiatric disorders
7.	Genomic editing	Translational	Treatments to modify course of disease	Future cell therapy for genetic and acquired diseases
8.	Circadian rhythms	Science	Daylight savings	Understanding role of rhythms throughout physiology
9.	Immune therapy	Translational	Glucocorticoids Immunosuppressives	Tailoring the immune system for treatment
10.	Affordable Care Act	Policy	Fee for service	Value-based reimbursement

there is inadequate reimbursement for strategies to improve outpatient management. Clearly, there are solutions to this type of dilemma, but they are slow to evolve, and few health care organizations are innovating in this space without incentives that either penalize readmissions or reward better outpatient management. Despite these characteristics of academia that resist change, we should also acknowledge that we are blessed with a culture that embraces and values innovation. Therefore, in contrast to many businesses that are driven predominantly by bottom-line financial metrics, I argue that academic medicine has an opportunity to adapt more effectively to disruptive forces. Indeed, this will be necessary for us to be thriving institutions long into the future. Remember that the average life span of a modern business is 15 years, and few survive more than 25 years. Universities and medical schools, on the other hand, measure their impact over centuries. For example, the medical school at the University of Pennsylvania will soon celebrate its 250th anniversary. In 2011, Massachusetts General Hospital celebrated its 200th year. These milestones are reminders of the importance of a long-term strategic perspective that embraces both tradition and change.

Examples of recent and current disruptive forces in science and medicine

Having made the case that we are subject to the forces of disruptive changes, whether technological or societal, I will provide 10 representative examples of relatively recent disruptive forces in science and medicine. Next, I will forecast 10 areas where these disruptions may occur in the near future, informed in part by the cutting edge talks at this meeting. Finally, I will provide a prescription for approaches that AMCs can employ to better identify and adopt innovation as a force for change (see Tables 1 and 2).

The role of ASCI/AAP in change management

Physician scientists and academic leaders are ideally positioned to recognize, embrace, and catalyze change. We have a unique perch in AMCs to visualize the needs and opportunities for science and medicine in the future. Our goal should not be to protect the current state, however appealing it may seem, but rather to discover what is possible and identify pathways for effective implementation. Indeed, we should seek disruption as a solution to some of our intractable problems. For example, imagine medicine today if scientists had not developed 3D imaging (e.g., CT, MRI) or recombinant drugs (e.g., insulin, hGH). It is in our self-interest to learn from examples of disruptive innovation in other fields and recognize that organizations content to preserve a seemingly robust enterprise run the risk of becoming obsolete.

In addition to communicating, without hyperbole, why new scientific advances are important and why the public investment in research is good for society, I would like to offer three themes through which we can shape the future evolution of academic medicine by embracing if not fostering disruptive forces, as science and policy changes will undoubtedly provide unanticipated advances and challenges.

1. Use diversity as a strategy to adapt to a changing environment. Diversity takes many forms — workforce diversity, diverse educational and life experience, diverse forms of AMCs, etc. Diversity is also manifest in the configuration of interdisciplinary teams. We should leverage interdisciplinary teams to catalyze breakthroughs. More than ever, collaborations between medical school faculty and faculty in engineering, computer science, business, and other disciplines will create the next wave of innovation. Imagine how nanoscience will change medicine or how biomedical engineering will continue to alter the course of neurosciences and sur-

gery. We are currently witnessing remarkable improvements in quality and safety by developing team-based approaches to clinical care, often involving interprofessional teams. As academic leaders, we should encourage and support these types of interdisciplinary collaborations.

2. Recognize transformative technologies and adopt them. Not all disruptive technologies will be beneficial or even survive. However, as cited in the examples I have provided, many will be truly transformative. AMCs should be early adopters of new technologies, particularly when they can accelerate science or enhance clinical care. In most cases, pilot efforts can be used to assess whether larger institutional investments are appropriate. We need to arm our faculty with the best tools for carrying out their missions — whether research, teaching, or patient care. Institutions that fail to stay at the cutting edge will be doomed to fall behind.

3. Be a driving force to implement strategies that bend the health care cost curve. The US economy and individuals are becoming progressively burdened by the high costs of health care. This is not sustainable in a global market. As academics, we must identify and be a driving force to implement strategies that bend the health care cost curve; if not, dysfunctional solutions will be thrust upon us. Opportunities for bending the cost curve include unnecessary billing and documentation, employing more preventive strategies, streamlining diagnostic and disease management approaches, reducing unnecessary variation and ineffective treatments, engaging other health care providers in team-based care, and appropriate use of medications, among many other approaches. Importantly, many innovations, such as vaccines and more targeted therapies, can reduce the costs of health care.

We should acknowledge that we are better at innovation than implementation. While many good ideas for improving the health of the population or the individual are fairly obvious, multiple forces impede implementation. For example, as long as reimbursement for preventive services, patient education, mental health services, and rehabilitation are low, we know that health systems will not develop robust services and these fields will struggle to attract the best trained people. Ultimately, policy changes will be needed, likely led by the public sector, i.e., Medicare, followed by insurance companies. AMCs cannot effect these changes on our own. However, we can lead by performing the research that demonstrates efficacy and improves quality of life — recall that the US health care system is ranked 37th in the world! We can also advocate by adhering to our principles of professionalism and making cogent arguments to support health care models that incentivize prevention, access, and effective health care.

As we consider these major themes, it is worth returning to the concept of an ecosystem for AMCs and how the forces of selection will influence our evolution. We should assume that diversity is a strategic advantage, and we should also assume that excellence will be rewarded, particularly when it is defined as providing societal value and lower cost. Diversity is one of our major assets in academic medicine. Workforce diversity among our scientists, physicians, and other health care providers is an important means to achieve innovation. We are increasingly developing team approaches to science, clinical care, and education. These include interinstitutional research groups such as the Alzheimer's Disease Neuroimaging Initiative or the Eastern Cooperative Oncology Group; interdepartmental approaches to managing clinical care through cardiovascular institutes, cancer centers, etc.; and interprofessional education involving physicians, nurses, pharmacists, social workers, and others. Institutions are diversifying risk by making investments in an array of innovative projects that can "quickly fail" or thrive. In health care delivery, these include pilot projects supported by the Center for Medicare and Medicaid Innovation. In biomedical research, these include support for transformative research via the high-risk, high-reward research awards from the NIH. Importantly, we have a diverse array of organizational structures and governance models for our health care delivery systems. These include population-oriented systems such as Geisinger and Kaiser-Permanente, specialty centers such as MD Anderson and Memorial Sloan-Kettering for cancer, integrated AMCs such as Penn, Johns Hopkins, or Vanderbilt, and government systems such as the VA. These diverse models are able to respond to local needs and forces as well as allowing us to experiment with novel approaches to health care in a manner that allows dissemination of successful models.

While diversity provides a long-term hedge against selective pressures, it is useful to underscore the importance of a proactive approach to shaping our future. I have emphasized the importance of disruptive technologies. In general, we have done an excellent job of recognizing these and embracing them — after all, we are highly competitive scientists and know how to use new tools to advance our work. More challenging is the third theme, to bend the cost curve. We know that economic forces will demand high-quality health outcomes at lower cost. Current reimbursement models, based largely on procedures or volumes of activity, are not sustainable and have misaligned incentives. It is therefore incumbent on AMCs to provide innovative models that deliver higher value at lower cost. We have access to enormous amounts of data about outcomes and variability of care. We can design disease management strategies that improve quality of life for patients with chronic diseases. We can work to better identify and manage the high-risk patients that currently generate an enormous fraction of health care expenditures. Most of these approaches will require collaborative efforts and greater transparency between providers, payors, and policy makers. In another dimension, we can use individualized medicine to enhance our diagnostic accuracy and tailor treatments with drugs that have a greater probability of efficacy with fewer side effects. In science, we also need to capture more fully the value of our research and steward the resources provided by the federal government and foundations. We do this now through impact factors and relatively soft economic analyses. However, much research has a long and sometimes serendipitous path before having societal impact. It is important for us to understand and communicate how we got from identification of HIV to new treatments or how a combination of public health and medical interventions has dramatically reduced deaths from cardiovascular disease and diabetes. We have ongoing challenges to provide health care that is balanced across specialties and geographic areas. As a profession, we need to align incentives, whether career satisfaction, financial, or lifestyle, to create self-correcting forces.

In thinking about shaping the future, it is useful to imagine what academic medicine may, or should, look like 25 years from now. A medical student begins her career knowing that she will incur no debt throughout training. Her education, during medical school and residency, is now supported by an all-payor contribution, which is remarkably small (~0.5%) in the context of overall

health care expenditures. She is multi-lingual, culturally mindful, and begins medical school with grounding in epidemiology, public health, and information technology in addition to traditional pre-med classes. It is understood that this support will involve a service contract in which she will commit to work in an area of identified need or in research, potentially seeing the value of a lifelong career in public service. Medical school has also embraced the importance of interprofessional education from the outset. Medical students work in teams that include other health care professionals who have complementary backgrounds. Medical education is increasingly focused on diagnostic skills, information management, leadership, communication, and coordinating teams. The role of the physician has evolved to focus on decision making and oversight of disease management to insure that individual patients, and the population as a whole, receive high-quality and compassionate care at lower cost. Clinical care has shifted fundamentally from a fee-for-service model to a blend of population-based health and highly differentiated, individualized medicine. Primary care now lives alongside of highly specialized medicine as a field that reduces risk and manages chronic diseases. On the other hand, experts in particular diseases continue to provide invaluable resources for patients with rare diseases or with new-onset diseases, again managing these costs effectively. Remarkably, the cost curve for health care has been blunted, even accommodating demographic changes and myriad new advances. Research has also evolved considerably. It is increasingly concentrated in institutions with access to advanced technologies and infrastructure. Clinical trials involving approved drugs or devices increasingly rely upon large, fully integrated, national data sets that allow efficacy or side effects to be captured in realistic patient populations and clinical settings. The power of biorepositories, bioinformatics, and genomics is now well established. These platforms are incredible enablers of unanticipated discoveries. Globalization has linked scientific groups across borders.

I would be remiss not to think about these concepts in the context of the AAP. What will be our fate over the next 25 years, and will we survive? The organization has an opportunity to shape its own fate by recognizing disruptive forces and creating an adaptive culture that adds value. In recent years, the AAP has embraced a more diverse array of specialties. As an example, we now have a larger number of members with expertise in epidemiology and health policy. The Council, which is responsible for selecting new members and planning the annual meetings, is now elected, embracing democracy after more than 100 years. The annual meeting remains one of the best venues for sharing science across fields — including disruptive technologies! The meeting has also embraced active participation by the American Physician Scientists Association, providing engagement of the next generation of physician-scientists. The content of the annual meeting remains broad, with outstanding presentations by exceptional scientists. With all of this said, we will need to continue to evolve in the face of disruptive innovation.

In closing, I have focused on disruptive innovation as a transformative force in science and medicine, emphasizing changes in technology as well as changes in policy. I posed the question of whether we, as leaders in academic medicine, can shape the outcome versus being subject to natural selection. Given our complex ecosystem, I suggested a proactive approach based on three themes: diversity in its many forms, early adoption of technology, and bending the cost curve. I encourage us to shape the future rather than to be seized by it!

Address correspondence to: J. Larry Jameson, University of Pennsylvania Perelman School of Medicine, 295 John Morgan Building, 3620 Hamilton Walk, Philadelphia, Pennsylvania 19104, USA. Phone: 215.898.6796; Fax: 215.573.2030; E-mail: ljameson@mail.med.upenn.edu.

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