REIMAGINING SCIENCE and the IVORY TOWER

By Kennan Kellaris Salinero

I had my big aha moment about the future of science and the supposed influence of "market forces" during a conversation with a first-year graduate student in molecular and biochemical nutrition at Berkeley. A brighter future for science will not be shaped by market forces or academia, at least not as they are currently organized. Rather, it will be shaped by the human desire for contribution.

Alexandra was disillusioned. She had left a biotech company in Boston where she had been doing research that purportedly furthered modern medicine's contribution to improve the human condition. However, without a PhD she would not be making decisions or driving the direction of research, so she had left her position in Boston to pursue the basic research path that a PhD at Berkeley could provide.

She had come to Berkeley to make a difference for humanity. She had presumed that Berkeley, one of the world's top research institutions, would be the ideal place to study the role of nutrition at the molecular level, within the cellular structures of the human body. What she found instead was a role in looking for drug candidates to chemically block, modify, or activate those cellular components. There was righteous indignation in her voice when we met at a coffee shop near the Berkeley campus: "Can

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This is the author's accepted manuscript of an article published in *Change: The Magazine of Higher Learning*, 50:1, 38-46. Available online at http://www.tandfonline.com/10.1080/00091383.2018.1413906.

you believe they want me to look for another druggable target for diabetes? Why aren't they looking at why diabetes is increasing so much in the first place?

Further, she knew full well that a PhD is no longer sufficient, and that she would likely follow her PhD with a low-paid postdoctoral scholar position. Only then would she be eligible to try for entry into a hypercompetitive job market, currently saturated with five PhDs for every faculty position and 60 percent of recent PhD graduates leaving science altogether.

While research at Berkeley seemed focused on developing more, better, newer drugs, Alexandra was decidedly not. Alexandra was driven, instead, by a strong belief in the foundational importance of the foods we eat and the value of understanding as much about this complex human/nutrition interaction as possible. Many young scientists share this willingness to subject themselves to demanding coursework, long hours, and challenges based on altruism rather than hopes for fame or fortune—both of which are rare in the scientific enterprise, in any case.

We should not dismiss the power of idealism—and its relative ubiquity. Although Alexandra would have been financially wise to remain a technician in a world of research programs run by PhDs, the work offered up by that "elite" is not what she feels called to do. This presents a fundamental dilemma. Not having a PhD consigns you to following the research plans and ideas of others, yet having a PhD makes you difficult to employ, in extreme competition with others who have followed the same call. Why aren't we, as a society, able to provide a place for the idealism of Alexandra and others like her? Surely we have enough worthy work to be done in service to humanity.

In Short

- Science is in an era of a hypercompetitive job market, with five PhDs for every faculty position and 60 percent of recent PhD graduates leaving science altogether.
- Current challenges call for a fundamental shift to new ways of thinking and working in science.
- The tech sector provides examples, not necessarily readily seen, that the scientific sector can use as exemplars for shifting from rugged, individualistic, competitive practices to the models of highly collaborative, transparent, vision-driven teams.
- Solutions to these challenges need to tap the ubiquity of idealism—particularly in the next generation of scientific workers.

STEM and STEM Education in America: The Market and the Ivory Tower

So, let's get to the root of it—neither the corporate nor academic worlds have produced science, technology, engineering, and mathematics (STEM) careers in America that best serve humanity.

Alexandra's cohort from the United States has grown up in an era of substantial impacts of science, both good and bad: sequencing the human genome, antivaxxers, GMOs, the promise of gene editing, and bioterrorism. Science is a central part of the American narrative. The conventional wisdom is that our huge push for more STEM education will lead America's youth to the promising jobs of tomorrow.

The media decries the decline of American competitiveness and the dearth of STEM-trained students in our workforce, pointing to a pressing need for a renewed edge in science and math in America as our students fall behind the rest of the world. For example, according to the National Academy of Sciences, STEM-related occupations represented a full 80 percent of all high-growth jobs projected for 2008–2018 (National Research Council, 2012). In 2012, advisors to President Obama warned that "the United States is now putting its future at risk by forfeiting its historical strengths in STEM education," (President's Council of Advisors on Science and Technology: Executive Office of the President, 2012). They further advised the matriculation of an additional 1 million college students with degrees in the STEM fields over the next ten years. The need for increasing the United States' science and math education focus has reached so far that even Sodexo, Walmart, and PepsiCo have launched their own STEM initiatives which were highlighted in the Diplomatic Courier's 'The Future of Jobs' Global Talent Summit held Jan 14, 2015 in Washington DC.

But where are these jobs? Why do companies like Walmart need scientists? They are looking for the "middle skills"—the analytical, math-based, and computer-savvy skill set needed in current professional jobs. Most employers beating the drum of the need for more STEM workers aren't really asking for students prepared to work as scientists or mathematicians, and they certainly aren't looking for the precise specialized research talents that come with advanced degrees.

This profound disconnect between an industry that calls for more STEM workers and the expectations of those who pursue science and math degrees leads to huge inefficiencies, workforce mismatches, and personal disillusionment. In 2014, for instance, the U.S. Census Bureau reported that a full 74 percent of those who have a bachelor's degree in a STEM major are not employed in STEM occupations. Academia is imparting knowledge; industry is looking for skills.

The Academy: Where Are(n't) the Scientific Jobs?

Faced with uninspiring prospects in the corporate world, scientists who want to apply their deep expertise and scientific methods to the service of humanity have difficulty finding a career path that allows them to. The ivory tower has its own version of this disillusionment. Our brightest and most ambitious students, those who answer the intellectual call of scientific research, follow the path to graduate school discover academia doesn't have its own master plan worked out. The long-term research careers they hope for are not to be found.

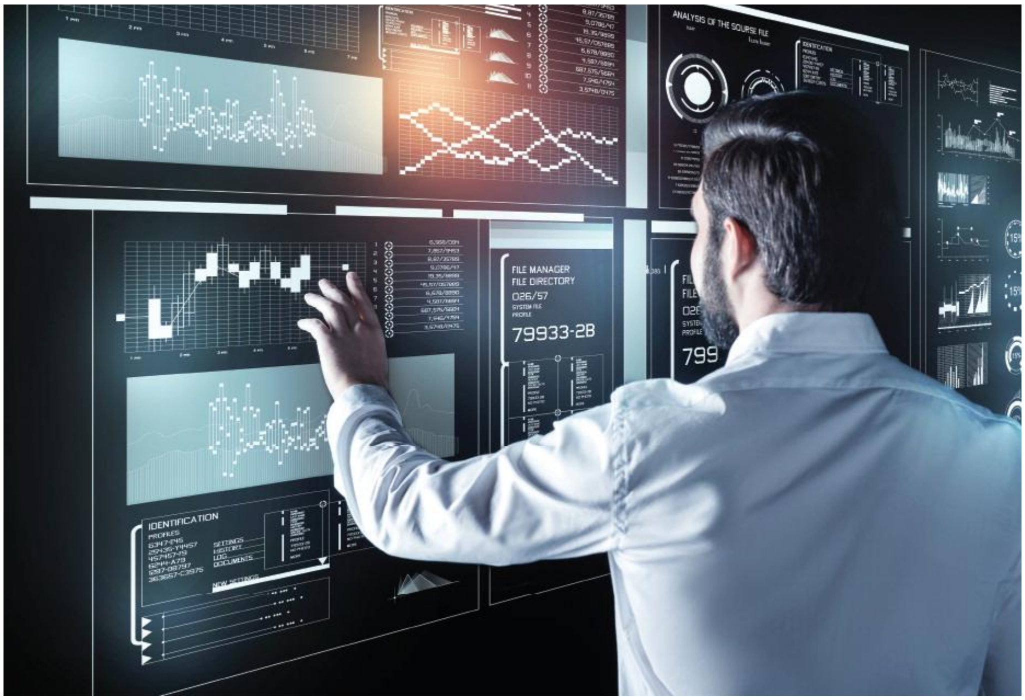
The deep desire to pursue PhD studies is understandable. Current scientific knowledge resides in universities; to truly learn our current depth of human knowledge in any area of science, one needs to pursue graduate studies. It is the ticket to be able to access scientific journals, learn advanced theory, and pursue experimental questions of fundamental principles. The treasure chest of all that we know, and all that we don't yet understand, lies sequestered in the exclusive environs of the ivory tower.

Yet this generation faces a landscape of great turmoil in the sciences. In 2014, a team of top scientists declared that biomedical science in the United States is unsustainable (Alberts, Kirschner, Tilghman, & Varmus, 2014). Inefficiencies in our system leave our best and brightest stranded in the career pipeline, well after they have invested over a decade of their prime career-development years training for jobs that don't exist.

This mismatch is a problem for the Alexandras of the world, yet alarmingly parents still steer overachieving children to the phantom job market since the issue is nearly completely unknown outside the hallways of academe and the underemployed PhD scientists trained there. Teitelbaum (2014) and Salzman (2013) have described academic science as a pyramid scheme; Stephan unflinchingly uses the term "Ponzi scheme" (2012). In 2015, a report from the Bureau of Labor Statistics noted there was no obvious shortage of STEM professionals, with an oversupply of PhDs in the academic job market, particularly in the area of the biomedical and physical sciences (Xue & Larson, 2015). Even for STEM-related occupations, 75 percent of occupations with the largest projected growth don't require an advanced degree, and some don't even require a bachelor's degree (Lacy & Wright, 2009, as cited in National Research Council, 2012).

There simply aren't enough jobs for PhDs in science. At the University of California, San Francisco, one of the top institutions in the biomedical science research enterprise, only 14 percent of its postdoctoral scholars attain the jobs for which they have been trained (Fuhrmann, Halme, O'Sullivan, & Lindstaedt, 2011). Career outcome metrics are rarely evaluated for this forgotten population, but the few studies conducted have found that less than one in seven postdocs get the job (tenure-track faculty positions) for which they have been trained.

Because of this oversupply of PhDs, it is not uncommon for senior scientists in the very agencies that oversee and support science to suggest that young scientists should not fool themselves about job prospects after receiving their doctorates. A refrain I commonly hear from policy and career advocates is, “They know the stats—they need to go in with their eyes open,” assuming that those statistics should act as a winnowing force.



They don't appear to be. Students are still answering the call for STEM-focused educational paths and for attaining the highest training possible in hopes of benefiting humankind. Sadly, once they are there, they find academic science in our modern technology-driven society is increasingly a destructively competitive domain. Although it once aimed for playing a large role in the eradication of disease, increased access to healthy foods, creation of low-impact energy sources, and an overall enjoyment of simply understanding the intricate beauty of the physical world, now it shoots for grants, publications, status, and job security. The extreme competition for those few jobs for which our current PhD population has been trained rewards only those willing to participate in a tournament model (Freeman, Solomon, Rosenbaum, Marincola, & Weinstein, 2001). There is a human cost to this that seems to be hidden—except to those inside the world of science.

One successful midcareer scientist describes academic science as a hypercompetitive world where 99 percent of scientists are driven by fear (Couzin-Frankel, 2013). Fear of what? The simple answer may be fear of not obtaining funding, fear of not keeping up the publication rate necessary for tenure, promotion, and losing one's place at the front of the pack. Or it may have deeper existential roots: fear of being largely irrelevant to deeper humanitarian impact, in spite of a highly demanding workload. Biomedical research science, an occupation that should have at its roots the profound contribution it can have to health and thriving, cannot thrive if at its core it is grounded in these strange incentives and this kind of pervasive fear.

Alexandra's seeming choice of only two unsatisfying futures—at the bench but not doing the level of work she was inspired to do, or attaining a PhD only to become less employable—is a problem for society as well.

Stepping back to view the state of science and the plight of many scientists, we are mistaken if we believe that science is just a little off track. From the scientific establishment's perspective, more cash from Congress will surely put us back on the right path. But pushing more money into a broken system might simply increase the inefficiencies and frustrations piling up within science and in the public's unease with science, exacerbating the deep disconnect between our scientific enterprise and society. At this point, even the standard levels of funding are under extreme risk. Changing the basic paradigm to finding new knowledge that can better serve the public seems further away than ever.

A Crumbling Foundation/Another Path: Systems Thinking

For Alexandra, the research projects she was being offered were narrow, uninspired, and simply would add another small brick onto a wall that she does not want to help build. Not only that, it is a wall whose foundation is loosening. The biomedical establishment is dealing with what is called the “reproducibility issue,“ first highlighted by John Ioannidis at Stanford University (2010a, 2010b) and further substantiated by the drug development company Amgen (Baker, 2016), and others.

The idea of an individualist incremental approach to “solving puzzles” has outlived its utility. Individual prowess falls woefully short in addressing complex, or “wicked” problems—a term defined by Rittel and Webber (1973) to describe problems that require new approaches because they involve multiple intertwined moving parts and interdependency, complexity, and open-endedness.

Of course, the vast numbers of people and the billions of dollars thrown at the scientific enterprise have indeed produced an incredible depth of knowledge—worthy of the Science Channel and NOVA. But we need to take seriously Alexandra's sense of a need for much deeper understanding of the many challenges to be addressed in the domain of health—rising levels of cardiac disease, asthma, and diabetes; the prevalence of malaria and tuberculosis; outbreaks of SARS, Ebola, Zika virus, and avian flu. Why aren't we able to provide freshly minted PhDs meaningful work? Instead, grants, publications, and individual scientific status have become proxies for progress while so many larger questions remain barely understood. The irony of lack of career pathways for newly trained PhD scientists is almost painful.

The failure to solve current health challenges and similar problems calls for a major change: a fundamental shift to new ways of thinking and working in science. In its current state, as a reductionist inquiry, science plugs along finding new pieces to add to “the” puzzle on a daily, and even hourly, basis but makes little fundamental progress against the headwinds of complexity. Our outdated belief in simple silver bullet answers creates blind alleys in the scientific process, adding increased complexity and slowing overall progress.

There are other ways. Complex systems like those that challenge us in science have been better understood using mathematical approaches under the rubric “systems dynamics,” a field born in the technical arena during World War II (Forrester, 1989). This field has developed to become “systems thinking,” embraced in many domains since its inception and further development by Forrester and others at MIT's Sloan School of Management. Systems thinking strives to identify outcomes, leverage points, and unintended consequences when working on interdependent problems that span multiple domains. The evolution of systems thinking has been adapted to business and engineering decision making, most widely popularized by Peter Senge in his book *The Fifth Discipline* (1990). Yet the scientific community seems oddly untouched by this offspring of its own methods.

Instead of thinking of solutions to the current problems of scientific inquiry, I suggest looking to *processes* for systems change to generate a shared engaged vision for the future of science. This approach would involve three basic premises. These would inform ways to generate new thinking about how change can be directed using the components already operating in a system, bring new ideas from other domains, and, where necessary, build from scratch in place.

Change must be derived from a process that includes a wide range of stakeholders from within the system itself to remain closely connected to reality. Dictating effective policy from outside a system that has so many interconnected moving parts does not work. The nuanced details operating at ground level cannot be sufficiently captured by assessments that inform top-down decisions.

For example, in *The Power of Positive Deviance* (Pascale, Sternin, & Sternin, 2010) describes a methodology that brings careful questioning and observation within a system to identify those yet unseen metrics that already support positive outcomes. Positive deviants, as they are called, are outliers in an existing system that have already found the path to producing desired outcomes. The trick is to find these outliers that exist in the native system and identify what was done differently to produce such results. Public engagement is an effective way to remain connected with reality.

Examples of public engagement partnerships in the creation of new technologies, new policies, and social equity can be seen across the globe. For instance, the Royal Society in England began involving the public much earlier in the development phase of new science and new technology. In hosting a year-long inquiry into the implications of nanotechnology, new voices were invited to the table to sit as equals with the scientific “experts” (an environmentalist, a social scientist, and a consumer advocate) (Wilsdon & Willis, 2004).

Other public engagement examples include the BBC World Service Trust report on its work to provide platforms and spaces where citizens from Iraq, Bangladesh, and Nigeria could create democratic change for themselves and their societies (Dowsing & Deane, 2011). Similarly, the World Bank finds that inclusion of the previously unheard marginalized peoples in society is necessary for equitable development (Das, Kyte, & Fisiy, 2013).

Don't go directly from problem to solution. Places of leverage (Meadows, 1997), informed by current reality, cannot be addressed with solutions from the past. A place of suspension, built into the question process, can allow completely new ideas to emerge. It is important that these ideas are concurrently informed by detailed studies. Attention to my first assertion—that all stakeholders help inform the questions—provides the necessary feedback from “reality.” Reality as it occurs to the stakeholders in the system is primary in importance. Good examples of this are Theory U and the Presencing Institute, which has close ties to the MIT group that evolved from Jay Forrester's work (1989), which builds the “gap” into its solution-finding methodology. Doing this steers thinking away from seeking top-down, “logical” solutions that only address individual elements of a problem and from a limitation of viewpoints that lacks sufficient diversity to mirror the larger system.

Explore and exploit creative tension—Robert Fritz's structural tension model. Fritz studied cultural creatives—music composers, painters, and other artists—in the New York area in the 1980s to uncover the processes leading to masterpiece outcomes. Though Fritz (1984) created his model to capture traits that lead to such high-level accomplishments at the individual level, the model is just as powerful for shared vision. Fritz's model proposes that success begins with a clear vision of the final outcome, which is then continually assessed to determine whether incremental actions are moving toward or away from the final goal. A key component of his action plan is to not collapse the vision toward current reality—rather, keep the vision clearly held and don't stop until it is fully achieved.

The importance of a “close relationship to reality,” pausing long enough to let a new vision emerge from within the community of stakeholders, and an internal mechanism that allows iterations and adjustments based on progress toward or away from that vision are processes that can inform a new way of organizing our scientific efforts.

Learning from Tech

Many of these processes occur in the tech sector. Approaches that include more diverse inputs, that have methods to reveal a sufficiently clear vision of "done," and that help teams stay together and open to solution finding can be found. These positive "deviants" can inform the possibilities of what can shift culture and collaborative excellence in science.

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For example, faced with the need to organize large teams of engineers to code Visual C++ at Microsoft, Jim and Michele McCarthy developed the McCarthy "Bootcamp," a training methodology to create shared vision and then a viable path for a group to attain that vision. Development of self, awareness of one's internal moods, and open sharing within a team setting with courage, authenticity, and accountability allowed the teams they have led to tap into shared passion and clarity of purpose (McCarthy, J., & McCarthy, M. 2002).

"Scrum" is another such development (e.g., Mayer, 2013); a good review can be found at http://alaverdyan.com/readme/tag/origins-of-scrum/). As early as the 1980s, Takeuchi and Nonaka (1986) observed that highly complex environments had spawned new holistic approaches to work teams in Japan and the United States that leveraged self-organization, co-learning, transparency, and on-purpose instability. The development of Takeuchi and Nonaka's explication of dynamic, lean, self-organized teams working in complex environments led to the five core values of Scrum (respect, commitment, focus, courage, and openness). These foster practices of transparency, collaboration, and strong feedback loops that include the customer base. Scrum and its parent organizational structure, Agile, exemplify systems-thinking approaches to getting work done in the technology sector. Organizing principles that allow employees to operate as self-organizing players in a complex systems-based approach are key to these workplace models.

Current barriers to fast-to-fail and quick-to-reorient strategies include individualist success metrics, lack of tools for dealing with complexity, and lack of access to information. Overcoming these issues would create a scientific workforce that experiences more meaningful, more efficient work.

In a restructured system, first, the individual scientist's need to continually prove independent prowess and capability would be replaced by redirecting energy to the (shared) production of knowledge, discoveries, or inventions that positively impact society. Without that competitive pressure, scientists can bootstrap from others' ideas before those ideas have gone through the long process of either publication or patents. Second, a shift from disciplinary work to working across disciplines is necessary in addressing

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complex challenges such as obesity. New habits and organizational structures of the workplace are required to build and maintain robust teams that have the requisite diversity of thinking styles and specialization. Scrum, as one example, employs open-feedback processes and two-week "sprints" of problem-focused interdisciplinary work cycles. Third, a scientific workforce that engages in open exchange of data and nuances of information with a society it has engaged with trust and authentic listening will have the basis for discovery within complex systems. The means for finding positive deviants through the staggering capability of artificial intelligence combined with big data is poised to allow scientists to once again ask important, meaningful questions of nature.

Systems-thinking approaches like these can bust silos and create vision-driven cohesive teams. Done well, they also open safe paths to discovering one's implicit biases and unconscious cognitive processes, allowing a group to have the necessary closer relationship to reality. Open dialogue between those who are stakeholders (nearly everyone), our future scientists, and policymakers can lead the way to a whole new level of understanding of human health and ultimately to a healthy thriving planet. Against that backdrop, it becomes easy to understand why a bright young person like Alexandra wouldn't want to be left on the sidelines.

A Different Future

The path to such a new vision of the work of science can already be seen, something like narrow cuts through the wilderness laid by early explorers—positive deviants at the academic-societal interface:

- MITACS in Canada connects academic discoveries with societal needs through corporations that are eager to develop the treasure troves of largely abandoned discoveries (https://www.mitacs.ca/en/about-mitacs).
- Samuel Merritt University recently sponsored a team composed of an academic, a programmer, and an inventor to design a process and associated software to create a shared vision of what their health sciences education should confer on its graduates, which they then mapped to qualitative and quantitative evidence of achievement, shared resources, and criteria (Bamford, P., & Landau, V. 2017).
- The American Association for the Advancement of Science has backed a trial program of graduate students to address complex societal issues as a team in their Emerging Leaders in Science and Society program (https://www.aaas.org/page/eliss-overview).

The funding of these early entries is tenuous. However, the relative cost savings for effective transfer of knowledge from the ivory tower to implementation, as opposed to the current exceptionally high failure rate due to human organizational factors (not the technologies themselves) is likely to draw the attention and support of the corporate sector over time.

Imagine a few years from now. Alexandra, a young researcher who also rotates into teaching stints at various educational institutions in her city—at the university, but also at one of the local grade schools—is just leaving a meeting on community health. The meetings have been occurring weekly since a spike in diabetes was noticed in the local youth population. She's a bit frustrated by the mother who couldn't see her way to financially afford fresh juices instead of much cheaper soft drinks for her kids. But she also remembers with a smile the input of the young man from a new nonprofit, Eat Your Veggies, who announced a program that would help alleviate the financial burden for this mother of five.

Two young members of Alexandra's research group are likewise enthusiastic after this particularly energetic meeting. One is working on community health center programs, which are creating a new project area via cook-ins at their center on Sunday afternoons. The other is getting exciting new results in early detection of inflammation response to insulin overload, allowing clear feedback on the issues that come with high-sugar diets. Daily fifteen-minute calls (or "stand-ups" to use Scrum terminology) include 50 different individuals from across the community—in governance, local businesses, the research community, health care cost watchdog groups, and the school system. The calls can seem chaotic but, after a few months of staying steady with them, they have proven to be a huge accelerator for feedback in their research and impact work.

Alexandra is eager to share the good feelings of her morning success with her son, who spends his days in the care and learning center in her research building, when she stops by to have lunch with him. And she is just as eager to share with officials at the National Institutes of Health whose thwarted attempts to improve health by issuing guidelines aimed at the American public was now gaining momentum for positive impacts through robust and productive partnership with that same public.

In the end, we absolutely need the energy of individuals who want to address the critical situations that face humanity. There is more than enough worthy work for us to do. In my experience our young generations of scientists are poised to work on big problems together. What are needed are places of employment that would allow next-generation scientists to flourish. The current path awaiting young scientists with degree in hand—fierce competition, where the reward is a publication or a grant, with little direct evidence of that work's impact on these larger problems—will no longer suffice.

We can harness that energy by finding where effective paths to rewarding work, productivity, and quantum leaps in understanding already exist: through listening to young people who have the excitement and energy to apply their gifts toward solving real problems they yearn to address; understanding society and the problems impacting it most; listening to the science-interested public, who wants help in applying the knowledge already gained by scientists; and finally asking ourselves what we really want, for our future and the future of our descendants and the planet.

It is a key moment for the planet and for humanity. If we don't get interested in discovering conjointly between the tech/corporate sector and the basic sciences what we mean when we say “STEM,” we risk falling further into a negative feedback trap. The strong visionary pull of “why,” of why we pursue scientific inquiry, can bring the challenges for humanity and the planet into clearer focus and best serve all of us.

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