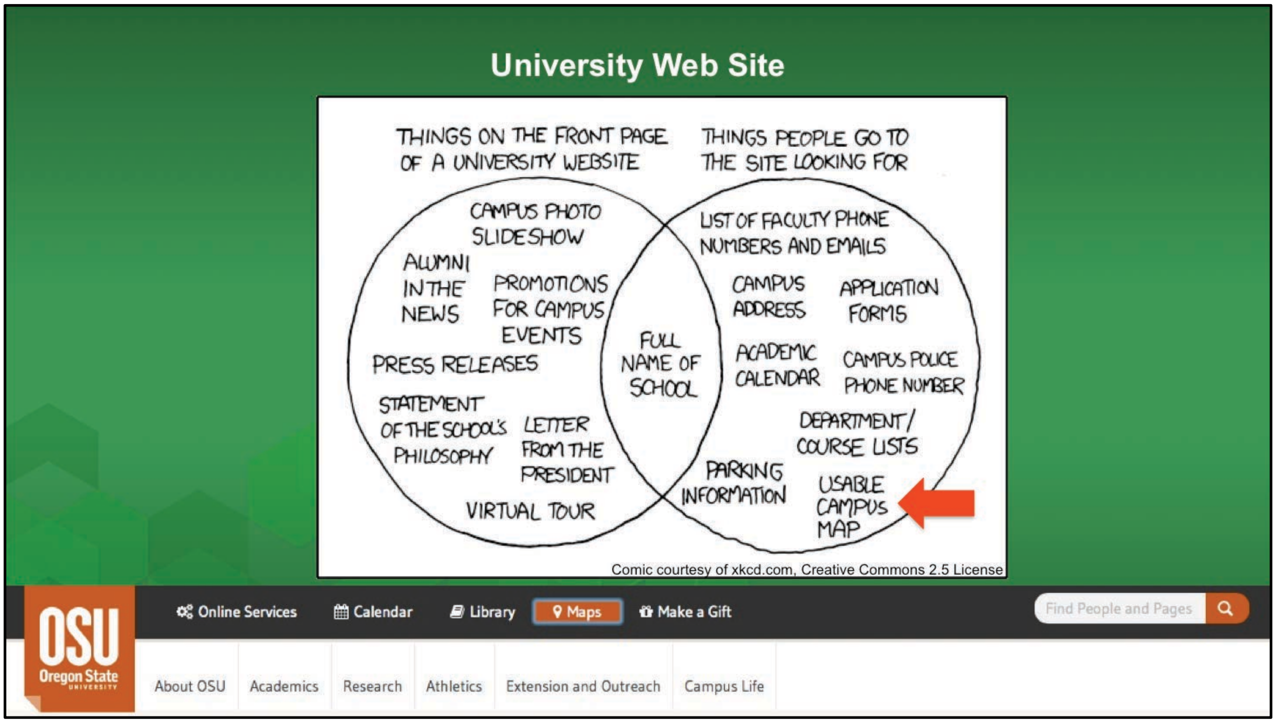
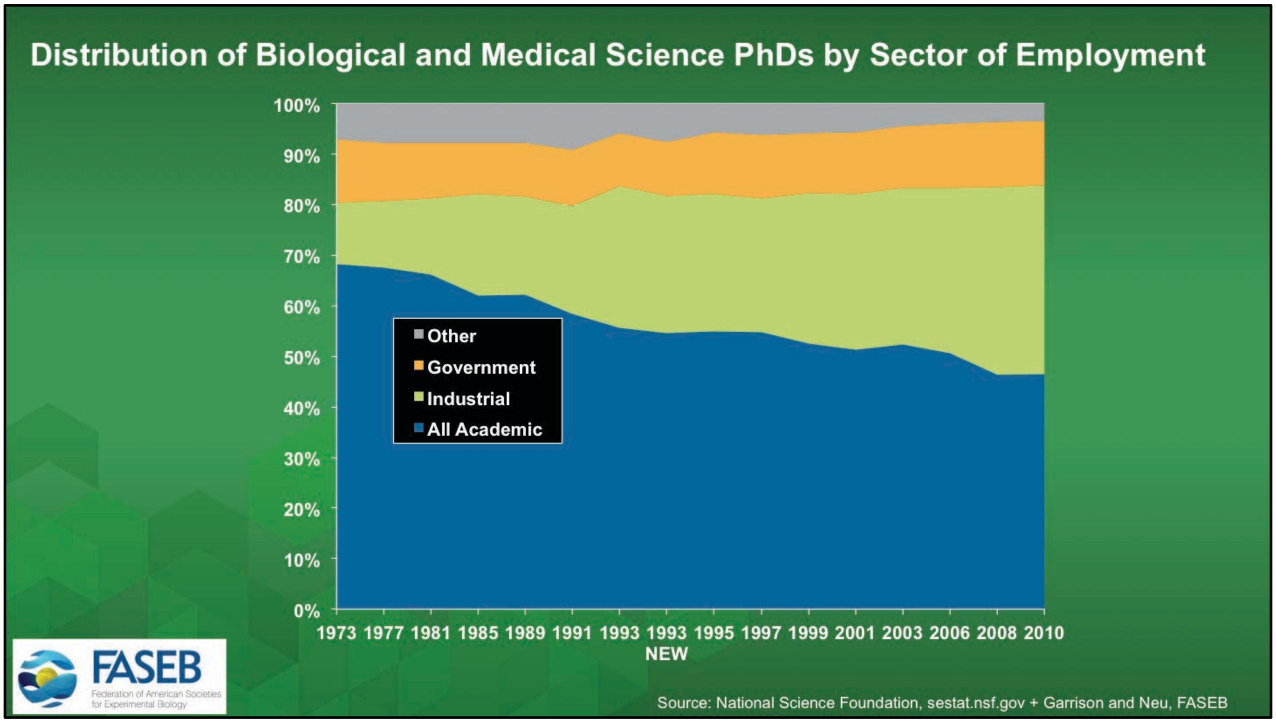
Scott Thomas' keynote focused on higher education at the broad, 30,000 foot levels of higher education (particularly it's high cost and how to remedy that). Anthony Robinson focused on *students* and the content that we provide *to* students, especially via MOOCs. In my remarks I'd like to focus on those in the trenches *with* the students: the instructors, professors, post-docs, even the graduate teaching assistants at colleges and universities worldwide. These remarks may also apply to instructors at the high school level, preparing students to enter college.



Higher education is well known for being innovative and forward-thinking, but at the same time for too often being DISCONNECTed.
Take the humorous example of many (most?) university web sites.
Shout-out to Oregon State University's web site which gets you directly to usable campus maps!

Comic: http://xkcd.com/773



Graph is an example from biomed but trend is similar in other sciences + computer/info science; based on extensive series of surveys by US National Science Foundation of millions of scientists & social scientists
FASEB = Federation of American Societies for Experimental Biology
Survey Notes: Since 1993, the response rates for the surveys have increased to 77-87%
Even in 2009-2010 at the height of stimulus spending the largest growth in academic employment was in non-tenure track positions

Graph actually should not be surprising, nor should it be normalized (see also the terrific blog, "Contemplative Mammoth," of asst prof extraordinaire Jacquelyn Gill, Geog PhD from UW-Madison now at U. Maine).

In addition, a recent analysis by the American Institutes for Research found that most Ph.D.'s in STEM Fields now work outside of academia (is this the case in other countries too?). The group's analysis of federal data shows that 61 percent of students in STEM fields have nonacademic careers, and that 43 percent of Ph.D.'s in those careers say their primary work activity is not research and development. The analysis was based on data about more than 400,000 people who earned doctorates in STEM fields from 1959 to 2010.

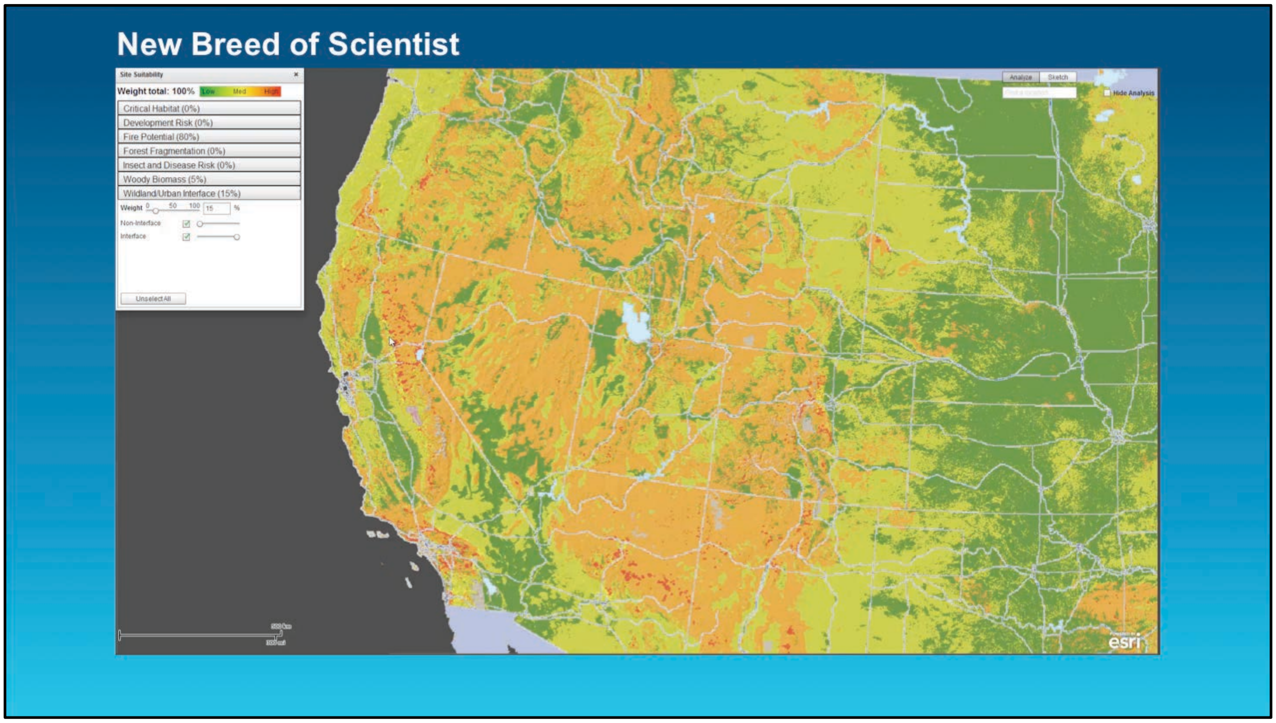
Students need training beyond the traditional "ivory tower," become-a-clone-of-your adviser. Gill: "Academia should be something you opt into, not out of."

Inspiration from the blog post of Jake Vanderplas, U. of Washington ("The Big Data Brain Drain and Why Science in Trouble"). He writes that the shift to data centric science has a dark side: "**the skills required to be a successful scientific researcher are increasingly indistinguishable from the skills required to be successful in industry.** While academia, with typical inertia, gradually shifts to accommodate this, the rest of the world has already begun to embrace and reward these skills to a much greater degree. *The unfortunate result is that some of the most promising upcoming researchers are finding no place for themselves in the academic community, while the for-profit world of industry stands by with deep pockets and open arms."*

A brain drain in any ONE DIRECTION direction is dangerous. Need people in BOTH academia AND other sectors in order to make progress (e.g., Esri as an industry leader needs innovation from academia)

- **Scheffer (2014) PNAS, Wageningen – the forgotten half of scientific thinking -** "many of the breakthroughs in science were made by people who were distracted." Academiia allows for that. What about the most innovative in industry?

Federation of American Societies for Experimental Biology press release in late 2013
NSF recently released new data from two national surveys. Together, these surveys provide an updated perspective on changes in training and employment in science, engineering, and mathematics.
Survey Notes: Since 1993, the response rates for the surveys have ranged between 77 and 87 percent.
Even in 2009-2010 at the height of stimulus spending the largest growth in academic employment was in non-tenure track positions

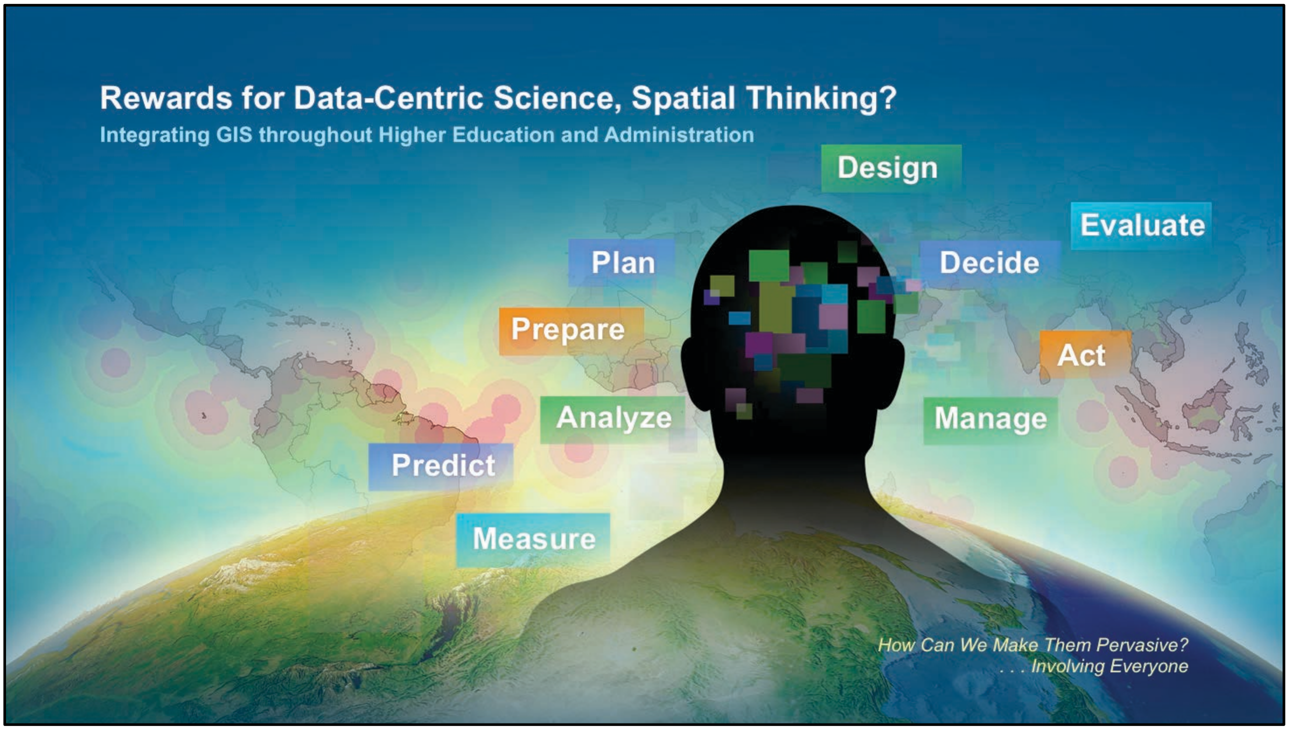


New breed of scientist must be a broadly-trained expert in statistics, in computing, in algorithm-building, in software design. GIS and GIScience very much a part of this. Professors are developing and using tools such as what you see here with Landscape Analyst (weighted overlays of large datasets provisioned as web services)

The Fourth Paradigm (Hey et al., 2009), which posits a new paradigm of scientific discovery beyond 3 paradigms of EMPIRICISM, ANALYSIS, and SIMULATION to a 4^{th} where insight is discovered through the manipulation and exploration of large data sets

data-centeredness of science

Slide shows web services in Landscape Modeler of areas susceptible to fire risk, how much is federal, state, demographic layer; weighted overlay (modeler) to show the highest risk for fire, then sketch on that (GeoPlanner) and see a valuation of the impact of that sketch; these are running in the cloud that people can subscribe to and use



Instructors and post-docs are building new curricula based on data-centric science and spatial thinking, training their students, doing MOOCs. Are they getting the proper credit toward promotion and/or tenure?

I came to Esri from a so-called blended department at OSU (not only geography but geography-geology in a geosciences dept – there are variations on that theme). I'm reminded of a colleague who took me to task for having a prereq in my GIS course, was insulted that his PhD student could not just get in w/o those prereq b/c after all isn't GIS just connecting dots on a map, and knowing which pretty colors to use? We need to continue change attitudes in the academy.

Academic disconnect where skills in research computing & programming are greatly needed by students but not properly rewarded by departments
Academic disconnect where industry IS rewarding these skills. Again, a **brain drain in any ONE DIRECTION direction is dangerous. We need people in BOTH academia AND other sectors in order to make progress in understanding our world.**

PERSPECTIVE

Changing the academic culture: Valuing patents and commercialization toward tenure and career advancement

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There is national and international recognition of the importance of innovation, technology transfer, and entrepreneurship for sustained economic revival. With the decline of industrial research laboratories in the United States, research universities are being asked to play a central role in our knowledge-centered economy by the technology transfer of their discoveries, innovations, and inventions. In response to this challenge, innovation ecologies at and around universities are starting to change. However, the change has been slow and limited. The authors believe this can be attributed partially to a lack of change in incentives for the central stakeholder, the faculty member. The authors have taken the position that universities should expand their criteria to treat patents, licensing, and commercialization activity by faculty as an important consideration for merit, tenure, and career advancement, along with publishing, teaching, and service. This position is placed in a historical context with a look at the history of tenure in the United States, patents, and licensing at universities, the current status of university tenure and career advancement processes, and models for the future.

promotion | intellectual property | start-ups | private partnerships

There is changing demand on academia to expand the research enterprise beyond just basic research and to contribute directly toward tangible economic development. Basic research is important for future innovation and funding should continue in this area. This position was well articulated recently by Leshner in his editorial commentary on the role of basic sciences in spurring innovation (1). However, societal expectations of universities now go beyond just research, teaching, and public service. University missions are expanding to include economic development, of which translation of university research is a major part (2). The greatness of a university is not just in its research grants and contracts metrics but also in how the university impacts and changes the world and society at large (3). To unleash the innovation potential of university research, there is a need for conducting scholarly activity that translates basic research into commercially viable processes and technology. However, addressing this need often requires faculty members with a different working mindset and modus operandi than those conducting purely basic research. It also requires engagement of the researcher in a period of translational work that does not necessarily result in outcomes that are traditionally counted in career advancement, such as publication.

Edison can be credited with being the inventor of the industrial research laboratory (at Menlo Park in 1876), and most of the use-driven national research and development that translated basic research into innovative products came from these kinds of industrial laboratories over the past century. As the 2012 report on research universities by the National Research Council of the National Academies notes, "business and industry have largely dismantled the large corporate research laboratories that drove American industrial leadership in the twentieth century (e.g., Bell Labs), but have not yet fully partnered with our research universities to fill the gap at a time when we need to more effectively translate, disseminate, and transfer into society the new knowledge and ideas that emerge from university research" (4).

Universities can and should take steps to bridge this gap and accelerate "time-to-innovation." A similar sentiment is echoed in the Advancing Research in Science and Engineering (ARISE) 2 report from the American Academy of Arts and Sciences, which advocates as one of their two broad goals, "the creation of an environment that allows flexible interactions among the academic, government, and private sectors throughout the discovery and development process" (5). The US Department of Commerce's report on "The Competitive and Innovative Capacity of the United States" lists as one of the 10 policy proposals the need to "speed the movement of ideas from basic science labs to commercial application" (6). The Research Universities Futures Consortium declares "The American research university has long been critical to the economic and social success of the United States. Expectations are high that academic research and innovations will play a central role in addressing current and future national and global challenges" (7). A recent report from the American Association of University Professors (AAUP) recognizes that "collaborations between industry and the academy present tremendous opportunities for advancing knowledge,

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applying it to real-world problems, and bringing about various social benefits. Cooperative research involving both university and industry scientists has proven critical to the development of numerous powerful methods, products, and technologies" (8).

The histories of academic tenure, invention, and patenting in the United States have become increasingly intertwined over the last 30 y. Some institutions, such as Stanford University, Massachusetts Institute of Technology (MIT), California Institute of Technology, Cornell University, and Georgia Institute of Technology, have an innovation-driven academic culture that has already made global impact through its start-ups and technology transfer. For such institutions, change in tenure and career advancement criteria may not be necessary. However, there are many universities where this innovation-driven cultural change is yet to happen, is happening at a slow rate, or spans only a small fraction of the faculty. For such institutions, merit, tenure, and career advancement criteria are important tools to affect change. Interestingly, the US National Science Board used patents—in addition to research articles—to measure academic research and development in their 2014 report (9). Their analysis also includes licensing income as a form of academic research and development output and patent citations to science and engineering literature as evidence of impact.

Should patenting and commercialization activities by faculty count toward merit, tenure, and career advancement evaluation? Should universities change the culture from research and publishing as the primary measures for career advancement and tenure to one that also recognizes academic entrepreneurs who translate their research into patents, licenses, and commercial products? A discussion of these questions is included in this article. We start by looking at the advantages of technology transfer, which extend beyond just revenue generation. We then consider current efforts to spur academic innovation and how, although necessary, they are not sufficient because of a misalignment of incentives. A brief history of tenure and promotion and the rise of the importance of patents and licensing at universities then provides historical context. We present evidence of faculty support for this change, followed by possible models for incorporating patents and licensing into tenure and promotion.

Advantages of Technology Transfer

Benefits of patents and commercialization have been articulated in recent articles (8, 10, 11, 12, 13) and extend beyond just direct revenue generation through licensing, and consist of advantages such as: increased opportunities for research funding, access to unrestricted funds for further institutional investment, sustaining high scholarship level, student success, increased prestige, public benefit, and economic development.

Increased Opportunities for Research Funding. Many funding agencies are starting to place emphasis on technology transition and translational research and development; for example, the National Science Foundation's I-Corps program, the US Department of Commerce's i6 Challenge grant program, and the NIH's National Center for Advancing Translational Sciences. Technology transfer activities help build long-term partnerships. "While that initial technology may never reach the market place, additional research contracts, student educational experiences, and potential employment opportunities will continue to develop" (10). There are also increased opportunities for university–industry partnerships. Because economic incentive programs exist around the world, technology transfer can be a bridge for international collaborations. An innovative and entrepreneurial branding of a university can help attract philanthropic funds and fund raising from alumni.

Access to Unrestricted Funds for Further Institutional Investment. There have been consistent increases in royalties of academic inventions in recent years (14). As reported in The Chronicle of Higher Education in August 2013, the Association of University Technology Managers' recent survey found that the total license income of 161 universities, 32 hospitals, and research institutes was $2.6 billion for the 2012 fiscal year (15). Although this total amount is not large when considered at a per university level, it provides universities access to unrestricted funds that can be used for further investment and expansion that would otherwise not be possible. Both the individual and the university benefit from access to these funds that can be reinvested in productive ways.

Sustains High Scholarship Level. Technology transfer activities are correlated with increased industrial connections. Studies have shown that faculty with industrial connections are academically more productive and have more impact than those without such connections (8). A survey of 3,080 life science faculty members found that those with industry relationships also published significantly more and in higher impact journals than those who did not have any industrial relationship (16). Papers published by university–industry collaborations are cited more than multi- or single university papers (17).

Student Success. Education of undergraduate and graduate students and postdoctoral trainees is a core mission of the university. Technology transfer activities provide students and trainees with unique exposure to real-world translational research experiences that connect with an immediate societal need, which is not available in the traditional curriculum structure. The student also gains valuable experience in the process of intellectual property management. The entrepreneurial spirit in the student is nurtured and encouraged, thus rounding off the university experience. Academic curriculum at the universities is also enriched by the inclusion of new courses on entrepreneurship, intellectual property, and technology transfer, opening up new possibilities for nontraditional students (10).

Increased Prestige. Technology commercialization through patents, licenses, and start-ups is a critical component of the dissemination of knowledge, falls under the umbrella of engagement, and is, essentially, an important part of being a university. Successful technology transfer brings recognition to universities and helps communicate, in a tangible way, the impact of university research, which might otherwise seem esoteric.

Public Benefit. Technology transfer helps strengthen the larger university mission of improving and uplifting the human condition by providing near terms solutions to social, medical, environmental, and technical problems. Innovations from universities have improved the quality of life for people in the United States and the world (e.g., the hepatitis B vaccine, the prostate-specific antigen test, Google, the Honeycrisp apple, and FluMist) (18). A larger list of university research-based companies that span technology and the Web, materials, manufacturing, biomedical, education, energy, and chemicals, and defense and safety is maintained by The Science Coalition at www.sciencecoalition.org/successstories-list.

Economic Development. From 1997 to 2007 university licensing had a $187 billion impact on US gross domestic product, a $457 billion impact on the US gross industrial output, and created 279,000 jobs (18). Many universities are also providing entrepreneurial training, product proof-of-concept support, and seed stage or gap funding to the local community, which contribute to local economic growth and retain local talent (10).

Current Efforts to Encourage Academic Inventors

To facilitate technology transfer in an efficient manner, the entrepreneurial ecology at and around universities has been changing. Rothaermel et al. provide an overarching taxonomy of the ecology in terms of the entrepreneurial research university, technology transfer offices, incubators, and surrounding innovation networks (19). Attempts to stimulate technology transfer directly include a number of mechanisms, such as technology transfer offices on university campuses becoming more actively engaged in soliciting disclosures from faculty, handling intellectual property, lowering the barrier of upfront royalty, sharing royalty and licensing income, internally investing in ideas, and establishing relationships with local businesses through student internships and research projects. A model example is seen at The University of Alabama at Birmingham's Institute for Innovation and Entrepreneurship, in which potential collisions between researchers and industry are encouraged to solicit the kinds of coalitions that would lead to intellectual property (20). Another example is the University of Minnesota's unique Minnesota Innovation Partnership program, which allows companies to sponsor research at the university with exclusive rights to any intellectual property produced by paying an upfront royalty. Such partnerships lead to a much deeper relationship and engagement that can ultimately lead to philanthropy and partnerships that are very significant (20). Some universities are exploring the use of the sabbatical leave process to encourage faculty to invest time into transitioning their technology to start up a company (21). Half of the universities surveyed in a National Council of Entrepreneurial Tech Transfer (NCET2) survey indicated that faculty are permitted to use sabbatical leave for this purpose (22). Although sabbatical leave is not discussed in depth in this paper, as it only occurs posttenure, faculty may have increased interest in attaining tenure to use sabbatical leave to pursue commercialization activities. Although it is clear that innovation in academia is a potentially lucrative and growing field and that tenure and career advancement are shifting as well, what has not been articulated until now is a clear national model for including academic innovation in tenure and career advancement decisions.

Efforts across the nation have resulted in significant impact in some cases, as exemplified by the list of 100 university research-based companies highlighted in The Science Coalition report, *Sparking Economic Growth: How Federally Funded University Research Creates Innovation, New Companies and Jobs* (23). However, results have not been widespread. Even after two decades, traditional academic culture, centered on publications and recognition from peers, has not changed.

Misalignment of Incentives

There is a fundamental disconnect between technology transfer activities and incentives to faculty members in terms of merit raises, tenure, and career advancement. Beyond the monetary benefit of licensing, which is small in most cases, there is little or no benefit to a faculty member's merit raises, tenure, and career advancement. Current policies, at best, mostly tolerate commercialization efforts. Only the few persistent faculty entrepreneurs consider building their careers along these lines, despite this misalignment of rewards. Renault rightly noted, "As long as the intellectual property, conflict of interest and tenure and promotion policies are not providing a consistent message for faculty about what is appropriate and desired behavior, the variety of actions shown in this study will continue" (24).

Based on 98 interviews spanning five research universities, Siegel et al. found that reward systems for faculty members, particularly untenured ones, are not aligned with institutional aspirations toward technology transfer (25). Interviewed subjects specifically reported that technology transfer activities should have a greater weight in faculty career advancement and tenure decisions. More recently, in a survey of 73 public and 28 private universities, Lach and Schankerman found a similar disconnect. "First, faculty in both public and private universities are well aware of monetary incentives from commercializing their inventions. Second, in the vast majority of cases in both public and private universities, faculty reward structures (salaries and promotion) do not give any significant weight to technology transfer outputs" (26). Nelsen and Bierer also see a need for change in career advancement and tenure criteria, especially for biomedical sciences, "as research moves further toward product development" (27). Traditional tenure and promotion criteria are also flagged by Pain as an impediment to investment by industry, which is an important source of funding as universities seek to diversify their research portfolios (28).

The merit, tenure, and career advancement process should reward applied scholarly activity and impact on society. Renault's 2006 survey on faculty entrepreneurship concluded that "until patents and spin-off companies are recognized as evidence of scholarly contributions, and used and not just tolerated in the tenure and promotions processes, the willingness of the faculty to spend their time on such activities will be considerably reduced" (24). The current academic emphasis on publications and research grants does not accurately capture use-oriented research, development, and technology transfer efforts. The American Academy of Arts and Sciences ARISE 2 report recognized this and recommended that universities "give greater weight to the public service criterion in promotion evaluations and consider knowledge export activities, including entrepreneurship, to be a component of public service" (5).

In 2011, Stevens et al. found 16 United States and Canadian universities that consider patents and commercialization in tenure and career advancement decisions, 5 y after Texas A&M officially declared commercialization as a sixth factor in their tenure considerations (14). This finding was corroborated 1 y later by a survey prepared by NCET2, which found that only 25 of the top 200 national research universities include patents and commercialization in tenure decisions (22). Stevens et al.'s survey revealed a number of striking similarities between universities that take patenting and commercialization activities into account when offering tenure and promotion (14). These universities are public institutions, they consider US patents a priority, they have adopted the policy in the last 6 y, and they publish their tenure and career advancement guidelines. The authors note that even the staunchest supporters of the inclusion of faculty patenting and commercializing activities into tenure and career advancement decisions agree that these activities should not replace scholarly pursuits, such as teaching and mentoring students and publishing research.

History of Tenure and Promotion and Patents and Licensing

Although academic tenure and intellectual property have not been historically linked, this paper serves to juxtapose the rise of tenure and promotion in an academic setting with the rise of academic patenting and licensing. The purpose of comparing these two histories is to set the stage for a discussion on the current and future role of commercialization in academic tenure and career advancement from both an individual and university perspective. Fig. 1 shows a timeline of important events. By the 19th century in America, tenure was an understood benefit, or gentleman's agreement, between distinguished university professors and the universities in which they were employed, and had existed as such for generations (29). Without contractual obligations however, universities were free to dismiss faculty at the request of their boards of trustees; "Before 1915, respected university presidents and boards of trustees had little hesitation in firing senior professors who took positions on great issues of the day contrary to the conventional wisdom" (29). Pressure grew for universities to seriously commit to academic freedom as a right of tenure with the rise of labor unions in the late 19th and early 20th centuries and several prominent cases of faculty dismissal.

One of the best known is the case of progressive economist Scott Nearing at the University of Pennsylvania in 1915. At the time, Nearing spoke out openly against industrial capitalism, claiming that "unfettered wealth stifled initiative and impeded economic advancement" (30). With a university board consisting of several corporate executives, Nearing's appointment as of June 1915 was not renewed, despite the disapproval of Nearing's fellow faculty members. Even before Nearing's noteworthy case, in January 1915 the AAUP formed a committee "to consider and report on the questions of academic freedom and academic tenure, so far as these affect university positions" (31). By December of that year, the AAUP formally published their "philosophical birth cry," the 1915 Declaration of Principles on Academic Freedom and Academic Tenure (29). The proposal described three end goals of academia: to safeguard freedom of inquiry and of teaching; to protect college executives and governing boards against unjust charges of infringement of academic freedom; and to render the profession (academia) more attractive by ensuring the dignity, independence, and reasonable security of tenure (31). It is important to clarify that although universities have academic freedom and tenure resolutions, all universities (both public and private) retain the right to dismiss a faculty member based on communication in their official capacity as an employee of the institution, as determined by the Supreme Court in *Garcetti v. Ceballos* (32, 33). The court reserved opinion regarding academic speech, and consequent lawsuits involving dismissal or tenure revocation have gone to state courts. As of now, there is no formal recognition of a legal right to academic freedom, and academic freedom remains a professional notion (32).

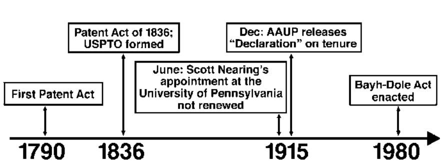

Fig. 1. Timeline of relevant historical events. USPTO, US Patent Office.

The development of patenting and intellectual property happened long before formal tenure policies. The Patent Act of 1790 was the first federal statute guaranteeing inventors "not exceeding fourteen years, the sole and exclusive right and liberty of making, constructing, using and vending to others to be used, the said invention or discovery" (34). Fast-forward nearly 50 y to the Patent Act of 1836 and the United States Patent and Trademark Office was formed. In the history of patents and intellectual property, perhaps the most relevant event for the purposes of this report is the enactment of the United States Code 35 USC § 200 et seq. in 1980, more commonly known as the Bayh-Dole Act. This act began as a 1978 conversation between then Senator Birch Bayh, a Purdue University alumnus, and Ralph Davis, then the director of the Technology Transfer operation at Purdue (20). Davis and Wisconsin Alumni Research Foundation Director Howard Bremer, with support from the NIH, made the case in Washington for what would become the Bayh-Dole Act.

Before Bayh-Dole, any intellectual property stemming from federally funded grants was obligatorily assigned to the federal government. As stated in the code, "It is the policy and objective of the Congress to use the patent system to promote the utilization of inventions arising from federally supported research or development. Each nonprofit organization or small business firm may, within a reasonable time after disclosure as required by paragraph (c)(1) of this section, elect to retain title to any subject invention" (35). The Bayh-Dole Act is of particular relevance because it creates a potential incentive for universities to promote academic innovation in gaining intellectual property and—potentially—licensing and profits. This may be especially true for public universities that have seen a 28% drop in state funding per student; in 11 states, state funding has been cut by more than one-third in the last 5 y alone (36). Similarly, one may see an act like Bayh-Dole as creating incentives for academics to pursue invention with the help of their institutions. Recent data on academic innovation may support this claim. According to the National Science Foundation, invention disclosures grew from 12,600 in 2002 to 18,200 in 2009, and new US patent applications filed by Association of University Technology Managers university respondents also increased, from 6,500 in 2001 to 11,300 in 2009 (37).

There Is Faculty Support for Change

Twenty years ago a 1994 national survey of 1,000 university professors from nine academic disciplines across 115 universities found that 72% of the respondents approved of faculty engaging in use-oriented research and 71% agreed to treating patentable inventions as refereed articles (38). A more recent 2013 survey by Goldstein and Rehbogen of 547 faculty members from 71 institutions confirmed this trend; only 20.3% of faculty members disagreed with rewarding "faculty for patentable inventions in tenure decisions" (2). Interestingly, according to this study only 10.9% of history faculty members disagreed with the recommendation.

One of the criticisms against the inclusion of patents and commercialization into tenure and career advancement criteria is the possible loss of free access to knowledge. However, studies have not found this to be the case so far. American Association for the Advancement of Science's project on Science and Intellectual Property in the Public Interest surveyed 1,111 American Association for the Advancement of Science members and found that patents were the most common means for protecting intellectual property (39). Dissemination of the protected intellectual property was through publication and informal sharing for 85% of the cases. Licensing of these patented technologies was a secondary mode of dissemination for a minority of the cases. About one-third of the respondents who did use licensing in the dissemination of their technology included a research exemption. For the minority of academic respondents who chose not to disseminate in any form, the top reason was plans for future research.

Possible Models for Change in Tenure and Promotion Criteria

There are many possible ways for incorporating patents and commercialization into merit, tenure, and career advancement criteria. For example, each college at Purdue has its own tenure and promotion document, and some specifically include patents and commercialization whereas others do not. The culture has been bottom-up and is dominated by local customs in the departmental committees (20). Under this model, as moods in the professions change, it permeates into the departments and eventually into the university. However, the model is too slow to be effective and ignores the leadership role that universities can play by explicitly including patents and commercialization activities in university-level tenure and career advancement documents.

Inclusion of patents and commercialization into tenure and promotion has begun at some universities, and examples of possible language in universities' tenure and career advancement criteria exist. We list additional language found through extensive Web searches in Table S1. If a university is not listed in this table, that does not necessarily mean that it does not value innovation. It may not be codified in the tenure and career advancement documents, or these documents may not be publicly available or found by us.

Within the tenure and career advancement documents of the 39 institutions in the table, language varied from strongly endorsing innovation activities to weakly stating that patents can be listed. Although, for most universities, patents and entrepreneurial activities are counted under research, a few consider it under service. In weak instances of inclusion, patents are simply listed as one of the many items than can count toward research and scholarly activity. In strong instances, the criteria are explicitly spelled out and more descriptive language that better captures the spectrum of entrepreneurial and innovation activities is provided.

Virginia Polytechnic Institute and State University is a good example of an institution with strong inclusion. As part of Research and Creative Activities, the tenure and promotion document explicitly lists what faculty members may include under economic contributions and entrepreneurship: "1. Start-up businesses (including competitive grants and contracts such as SBIR [Small Business Inovation Research] awards and other notable business achievements), 2. Commercialization of discoveries, 3. Other. . .Intellectual properties: 1. Software, 2. Patents, 3. Disclosures (prepatent)" (40).

The University of Arizona explicitly recognizes, along with research contributions, "integrative and applied forms of scholarship that involve cross-cutting collaborations with business and community partners, including translational research, commercialization activities, and patents" (41).

Other examples of institutions with strong language include Texas A&M, University System of Maryland, University of North Carolina–Greensboro, University of Minnesota, University of Nebraska Medical Center, Arizona State University, The University of Arizona, North Dakota State University, The Ohio State University, and the New Jersey Institute of Technology (Table S1).

There is sometimes an implicit assumption that patents and licensing only impact the science, engineering, and medicine sides of a campus. However, there are also interesting models on the arts and humanities side of campus. For example, the University of Michigan School of Music includes the following language, from a memo from former provost Phil Hanlon, in their tenure and promotion document: "Full recognition, both in evaluating tenure and promotion cases, will be given for a broad range of entrepreneurial, outreach and creative activities in which faculty engage. These activities may enhance any of the criteria on which faculty are measured—teaching, research and service. . . Examples are . . . creating a start-up company that enhances the broader scholarly, public service, or health care missions of the University, . . . creating new or enhanced practices, products or services, working with the Office of Technology Transfer to patent or license an invention, encouraging and instructing students in entrepreneurial and public service activities, developing collaborative approaches to solving complex world problems" (42).

Measuring the impact of patents and commercialization in the context of tenure and promotion is not immediately obvious. Even universities that have a long history of leadership in technology commercialization still struggle with how these activities are valued and how to measure their impact and that value (20). However, a starting point can be an array of indicators, such as: (*i*) industrially sponsored research projects; (*ii*) disclosures submitted; (*iii*) patents filed; (*iv*) patents issued; (*v*) licenses executed; (*vi*) license income received; (*vii*) Small Business Innovation Research/Small Business Technology Transfer, and other technology transfer-related grants and contracts; (*viii*) companies started; and (*ix*) knowledge of innovation and commercialization imparted to students through coursework, certificate programs, and guided entrepreneurial activities. If promotion and tenure committees are measuring impact, they will value those accomplishments that best demonstrate impact, eventually taking us beyond the tabulation of commercialization and entrepreneurial activities to a point where invention disclosures may have relatively little value, patent applications slightly more, and licensed patents will be highly valued, especially those that produce royalties (20).

Another way to measure impact could be through third-party awards and honors. For the very few and most-accomplished academic inventors, there are avenues for national level recognition, such as the National Medal of Technology and Innovation and the Lemelson-MIT Prize. The United States Patent and Trademark Office recognizes the most highly accomplished inventors, some of whom are academic inventors, by inducting them into the National Inventors Hall of Fame. Table 1 shows the numbers of awards per year from 2008 through 2013. However, until recently there was neither any national

Table 1. Number of specific national level recognition awards for all inventors and academic inventors from 2008 through 2013

	Lemelson-MIT Prize		National Medal of Technology and Innovation		National Inventors Hall of Fame		National Academy of Inventors Fellows	
Year	No. awarded	No. academic inventors	No. awarded	No. academic inventors	No. awarded	No. academic inventors	No. awarded	No. academic inventors
2013	1	1			17	7	143	143
2012	1	1			10	4	101	101
2011	1	1	10	7	39	7		
2010	1	1	5	2	16	4		
2009	1	1	6	1	15	2		
2008	1	1	4	1	19	6		
Total	6	6	25	11	116	30	244	244

level organization nor recognition for the nation's many other top academic inventors. To change this, the National Academy of Inventors (NAI) started the NAI Fellows program. This program touches many more academic inventors and institutions. To date, there are 244 NAI Fellows representing more than 120 universities (43).

Concluding Remarks

The academic culture, which has a very high inertia, must change from recognizing only basic research to rewarding use-oriented research, development, and commercialization as well. Future efforts should encourage this culture change by developing advocates for commercialization activity. We also have to research and experiment with ways to actually operationalize these tenure and career advancement recommendations at the level of the academic department, whose decisions and rationale form the core basis of final tenure decisions. The NAI and its university members throughout the United States can play an important role by encouraging innovation and bringing attention to the devalued role patents currently play in the process of tenure acquisition and career advancement at universities.

Tenure is about faculty being able to speak the truth and do what they believe is fundamentally important; the most important measure for success is the impact they have (20). This impact can come from basic research that drives further discovery or from direct solutions to society's problems through inventions. We must encourage bright, young faculty to consider the possibility of transitioning between both roles throughout their careers. Ten years from now, the university culture will be, or should be, much more proactive in terms of nurturing ideas and trying to identify the ones that have the most potential to impact society, as well as being more active in finding resources to bring those ideas to reality (20).

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Supporting Information

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Table S1. Language used to incorporate entrepreneurial activities in tenure and promotion documents at universities

Institution	Date founded	Public/private	Tenure and promotion language
Auburn University	1856	Public	"Evaluation of Research. . .Other indicators of research productivity which can supplement one's record include external grants and the creation of intellectual property, copyrights, and patents" (1).
Carnegie Institute of Technology at Carnegie Mellon	1900	Private	"Research: Measures of excellence in this area include the quality, volume, and impact of publications, including papers, monographs, books and research reports; evaluation of research by others; patents; prizes and awards for research; solicited and invited lectures; the amount of financial support; and the contribution of the candidate's work towards the needs of society" (2).
Clemson University	1889	Public	"2.) Scholarship (refereed scholarly work is weighed much more heavily), as indicated by the following possible supporting evidence: 2.6.) Patents awarded" (3).
East Carolina University	1907	Public	"Research/Creative Activity:. . .Patents" (4).
Florida Atlantic University	1961	Public	"Evidence of achievement in the appropriate discipline(s). . .where appropriate, patents and research grants" (5).
Florida Institute of Technology	1958	Private	"Research/Scholarly Activities:...List and describe briefly any disclosures of inventions or resulting patents" (6).
Florida International University	1965	Public	"Research/Scholarship/Creative Work: e. Patent Disclosures/Applications/Awards: Patent disclosures, applications, and provisional and final patent awards should be listed. If there are co-investigators on the disclosure, application or award, these should be indicated" (7).
Kent State University	1910	Public	"Evidence of the scholarship of discovery, integration, application and teaching, as well as university citizenship. . .In addition, candidates are expected to provide documented evidence which may include. . .. evidence of outstanding achievement, such as awards, patents, and copyrights" (8).
Lehigh University	1865	Private	"Publications and Creative Activities: Creative Activities:. . . Original designs, plan, inventions, and patents" (9).
Lincoln University	1866	Public	"Scholarly Research/ Creative Activity and Professional Achievement:. . . Documentation of externally funded grants and inventions and patents. . ." (10).
New Jersey Institute of Technology	1885	Public	"A complete curriculum vitae documenting publications and patent applications since appointment or last promotion. . .Applications for, and granting of patents and copyrights are recognized as a measure of importance and/or peer evaluation of the work in the field" (11).
North Dakota State University	1890	Public	"[T]he development and public release of new products or varieties, research techniques, copyrights, and patents or other intellectual property. . ." (12).
Northeastern University	1854	Private	". . .the receipt of patents represents professional recognition of research activities. In some fields technical, procedural, or practical innovations made clinically or professionally are evidence of productive scholarship" (13).
The Ohio State University	1870	Public	"2. List of creative works pertinent to the candidate's professional focus:. . .Inventions and patents, including disclosures, options, and commercial licenses" (14).
Oregon State University	1868	Public	"Authorship of a patent in the faculty member's field is considered as evidence of creative scholarship" (15).
The Pennsylvania State University	1855	Public	"Other evidence of research or creative accomplishments as appropriate (patents, new product development, new art forms, citation index analysis, etc.)" (16).
Purdue University (Consumer Sciences and Retailing)	1869	Public	"Benchmarking Excellence: . . .Patents and license agreements resulting from research done while at Purdue" (17).
South Dakota State University	1881	Public	"Examples (non-exhaustive) of publications or activities of research, scholarship, and creative activity:. . .patents," (18).
Stevens Institute of Technology	1870	Private	"Scholarly activities:. . .patents" (19).

Table S1. Cont.

Institution	Date founded	Public/private	Tenure and promotion language
Texas A&M University	1876	Public	"Patents or commercialization of research, where applicable" (20)... Patents are listed under "Other Research, Scholarship, or Creativity Accomplishments," in the faculty summary table (21).
Texas Tech University	1923	Public	"Evidence of research and creative activity includes print or electronic publications, non-print presentations, funded grant applications and reports, patents and other intellectual property, curatorships, and artistic productions and performances. Textbooks and innovative instructional materials having significant value beyond this campus may be considered contributions to research and creative activity" (22).
The University of Alabama at Birmingham	1969	Public	"Although scholarly work takes many forms, including design, basic and applied research, and other creative activities, a faculty member's effectiveness can be demonstrated by such achievements as ...patents, and the like. The quality of the individual's scholarly approach, capacity for independent thought, originality, and products of scholarship must be addressed" (23).
University of Arkansas at Little Rock	1927	Public	"The Scholarship of Integration may result in a traditional academic product such as an article, book or presentation. It also may take the form of a product or patent. As in other areas, appropriate forms of external review must be used to determine the merit of such products" (24).
University of Arizona	1885	Public	"...promotion and tenure reviews, as detailed in the criteria of individual departments and colleges, will recognize original research contributions in peer-reviewed publications as well as integrative and applied forms of scholarship that involve cross-cutting collaborations with business and community partners, including translational research, commercialization activities, and patents" (25).
University of Colorado Denver	1912	Public	"Research and/or Other Scholarly Activities:...Patent or patent applications" (26).
University of Houston	1927	Public	"Generation of intellectual property: List any patents issued or pending including patent number, date of filing, and status (provisional, non-provisional, issued)" (27).
University of Illinois at Urbana–Champaign	1867	Public	"Publications and Creative Works:...H. Patents " (28).
University of Maryland System	1856	Public	"Original Designs, Plans, Inventions, Software and/or Patents" (29).
University of Michigan School of Music	1817	Public	"Full recognition, both in evaluating tenure and promotion cases, will be given for a broad range of entrepreneurial, outreach and creative activities in which faculty engage. These activities may enhance any of the criteria on which faculty are measured – teaching, research and service... Examples are ...• creating a start-up company that enhances the broader scholarly, public service, or health care missions of the University,...• creating new or enhanced practices, products or services, • working with the Office of Technology Transfer to patent or license an invention, • encouraging and instructing students in entrepreneurial and public service activities, • developing collaborative approaches to solving complex world problems" (30).
University of Minnesota	1851	Public	"[I]nclude significant publications and, as appropriate, the development and dissemination by other means of new knowledge, technology, or scientific procedures resulting in innovative products, practices, and ideas of significance and value to society" (31).
University of Nebraska at Omaha (Medical Center)	1869	Public	"Evidence of Scholarly Activity: ...A complete listing of patents, patents pending, and any licensed products are also required in this evaluation.... Scholarly activity should be accepted in its broadest sense, and should not be viewed solely as basic or clinical research as acknowledged traditionally.... recognize as scholarly activity the development of innovative teaching methods, the synthesis of new concepts based on data already published by the candidates or others, technology transfer successes, software design, website design, or other activities related to information sciences, etc." (32).
University of North Carolina – Greensboro	1891	Public	"Research and creative activities may include, but are not limited to, the following:...Developing innovative solutions that address social, economic, or environmental challenges (e.g., inventions, patents, products, services, clinical procedures and practices)... Granted patents, Patent applications, Disclosures of innovation, Entrepreneurship and related activities..." (33).

Table S1. Cont.

Institution	Date founded	Public/private	Tenure and promotion language
University of Saskatchewan	1907	Public	"Evaluation of research, scholarly and/or artistic work for tenure and promotion at all ranks will address the quality and significance of the work. Evidence will include the peer-reviewed publications and presentations referenced above, but may also include other works (e.g., artistic works, performances, research related patents, copyrighted software and audio-visual materials)" (34).
University of Southern California	1880	Private	"While patents cannot replace peer-reviewed publications in a candidate's dossier, they are a sign of impact and productivity and will be considered accordingly" (35).
University of South Florida	1956	Public	"Other Creative Activities...Patents and Licensing...Other unique or entrepreneurial activities of significance" (36).
University of Wisconsin Madison	1848	Public	"[E]vidence of research performance and of a candidate's standing in a discipline includes ...(9)patents or evidence of intellectual property. The case must be made as to the quality and level of contribution of the candidate's present work" (37).
Utah State University	1888	Public	"Research or creative endeavors encompass a wide variety of scholarly activities that lead to the advancement of knowledge and/or to original contributions in the arts and humanities. Documentation supporting such activities must include peer recognition of their value and may include, but is not restricted to:...intellectual contributions represented by patents, inventions and other intellectual property" (38).
Virginia Polytechnic Institute and State University (Virginia Tech)	1872	Public	"Economic contributions and entrepreneurship: 1. Start-up businesses (including competitive grants and contracts such as SBIR awards and other notable business achievements), 2. Commercialization of discoveries, 3. Other...Intellectual properties: 1. Software, 2. Patents, 3. Disclosures (pre-patent)" (39).
Washington University at St. Louis (Sam Fox School of Design & Visual Arts)	1853	Private	"Other kinds of recognition for research may include patents, production or product development contracts, and demonstration of influence through citations, papers, awards, graduate student support, and the ability of the research to attract further funding" (40).

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OPINION

The forgotten half of scientific thinking

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Although thinking is the core business of scientists, we rarely ponder how it thrives best; this is ironic, as there is abundant scientific insight to draw upon. For example, it is now known that thinking has two complementary modes: roughly, association versus reasoning (1). We systematically underestimate the role of the first (1), and the way our institutions, meetings, and teaching are organized heavily reflects this imbalance. By contrast, many of the greatest scientists systematically nurtured a balanced dual-thinking process. We should follow their example and reform scientific practice and education to catalyze the unusual combinations of knowledge that often turn out to have the highest impact (2).

Although the precise physiological basis of the two aspects of cognition is not yet resolved, it has become clear that the complementary mode to rationality is the "associative machine" in our brain. The capacity to make remote associations is linked to creativity (1). This capacity varies between persons, but also depends on our state of mind. For example, ideas may come while falling asleep, peeling potatoes, or walking. In fact, Charles Darwin had a special "thinking path" close to his house where he used to stroll twice a day to promote his thought. Recent experimental work confirms that our capacity to make novel associations is boosted by rapid eye-movement sleep (3) and by undemanding activities that allow the mind to wander (4). This finding suggests that it may be good in a daily routine to alternate our cognitive work with naps or activities conducive to mind wandering.

However, to let the associative machine come up with useful new ideas it needs to have good elements to connect. Darwin's walks could generate his groundbreaking insights only because his mind was loaded with a rich array of life-long observations and ideas, which raises the questions: How can we best provide our minds with elements that might combine into crucial novel insights?

A study of 17 million scientific articles recently showed that the highest impacts often come from work that is well-grounded in a field of research but at the same time involves an unusual link to another field (2). Why are such influential links so unusual? How can we feed the associative machine in our brain with potential elements for such unexpected links? This is a tantalizing problem, because if the connection should be unexpected one cannot plan for it. Should we just allow curiosity to guide us on a random walk and collect elements for our associative machine on the way? Perhaps we should. As Nobel Laureate Kenneth Arrow, known for his many revolutionary contributions to economics, phrased his attitude in a conversation we had: "It is so far from anything I do, I *must* be interested." The idea that such a broad interest can be productive fits with the finding that winners of the world's top science prizes had, without exception, internalized a lot of scientific diversity (5).

However, if novelty arises from diversity, why does institutionally planned interdisciplinarity so rarely generate the sparks we hope for? Why do unplanned, random encounters seem to be more productive in this respect? This seems frustratingly uncontrollable, but unusual encounters can be promoted too. Small interdisciplinary institutes, such as the South American Institute for Resilience and Sustainability Studies, Santa Fe, and Janelia Farm, may have the best cards for that, although on a traditional campus simply creating irresistible informal places with nice food or free coffee may already catalyze a lot of unplanned cross-disciplinary encounters (5).

It may feel uneasy to count on the unplanned, and risky to pursue remote associations, but this is calculated risk. When I was discussing these ideas with Kenneth Arrow, he stated: "If you are not wrong two-thirds of your time, you are not doing very well." He added, "if you are wrong you had better find out yourself, not only because it is more pleasant, but also because it helps you to learn." Indeed, solid scientific skills are needed to weed out right from wrong. However, our current teaching and routines are focused almost exclusively on those skills, whereas the best science tends to come from a balanced mix of rationality and adventurous association. Why is half of that mix so hidden? If we know unexpected associations are important, and we know how they can be facilitated, why not act accordingly?

Marten Scheffer.

The idea that taking walks, reading things unrelated to your research, and hanging out with strangers in a campus pub should be considered part of the serious process of thinking, but might well meet with skepticism in practice. Should we really set time and space apart for things that distract us from our jobs? Yes we should, because many of the breakthroughs in science were made by people who were distracted.

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