Scaling Science

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The huge expansion over the past century in the amount of science being done has strained the original collegial system of review by peers with detailed knowledge of the strengths and weaknesses of the methodologies and their practitioners.

Once upon a time, students earned doctorates based on one major body of research published in a monograph; then they took up employment as professors based on their ability to teach. A small fraction of those faculty continued to do research, mostly as an avocation, often funded by personal resources or wealthy patrons.

About 60 years ago, societies realized that basic research was important enough to fund publicly, greatly expanding the amount of research and its economic importance to universities, which used the revenue to support infrastructure, graduate students and expanded faculties. Faculty became dependent on such fund-raising success for their salaries and promotions. This motivated faculty to apply for multiple grants, inevitably lowering the success rate for grants, which then motivated reapplications. This resulted in an exponential growth of the numbers of grant proposals that had to be reviewed, inevitably reducing the quality of the reviews. That led to reviews based on quantitative measures of productivity rather than intimate knowledge of the quality of the underlying science. That led to researchers publishing "salami slices" rather than definitive monographs, resulting in an exponential growth of the numbers of manuscripts that had to be reviewed, inevitably reducing the quality of those articles and their review process. It also produced an exponential growth in doctoral graduates hoping to find jobs in a research establishment that couldn't grow exponentially forever. Recent studies show that less than 5% of post-doctoral fellows will wind up in academia.

As a rough estimate, I would guess that since the 1960s, the rate of important scientific advances has increased at least 10-fold while the number of people involved in scientific research

Peer Review by the Numbers

In the 1970s, a faculty member with an active research program might have one grant that ran for 5 years and that had at least a 50% success rate for renewal. A community of 100 such grant holders would then be generating 40 proposals per year that required peer review. Such a light load could easily be reviewed by the best and brightest of the grant-holding peers. If the reviewers were selected from the 5% of researchers whose knowledge and achievements were two standard deviations above the mean, those reviewers would have to review only 8 proposals per year on average, an easily sustainable responsibility.

Successful university faculty now must carry multiple grants with a range of durations from various governmental, industrial and philanthropic agencies to guarantee stability of larger labs despite much lower success rates. The typical successful lab now might attempt to carry 4 grants at once with a mean duration of 4 years and an application success rate of 10% at best. A community of 100 such grant holders will thus be generating 1000 grant proposals per year. Even if reviewers are each willing to review 20 proposals per year, the pool of reviewers will have to be extended to include 50 of the 100 researchers in the community (i.e. everyone at or above the mean), a rather unselective criterion for such a vital task.

has increased about 100-fold. Great science used to be concentrated in a few institutions that nourished the culture and facilitated interpersonal communication; now it is distributed broadly and facilitated by email and teleconferencing. So while the amount of great science has certainly gone up, its density has certainly gone down. This changes the culture at all institutions, whether at the top or the bottom of the pecking order.

No one thinks we should go back to science as a hobby. On the other hand, no one designed the system we now have; like Topsy, it “just growed.” If we extrapolate these trends forward another 20 years, the quality of life and careers in academic research looks rather unappealing. The most talented students, upon whom the advance of science ultimately depends, might well decide on careers in other professions. Concerns are rising about derivative, erroneous, even fraudulent science from practitioners motivated by careerism rather than curiosity and calling. On the positive side, the sheer volume of money and science and supporting commercial suppliers of technology has greatly increased the productivity of those talented researchers who survive this system. It seems likely that the machinery of science will be very different 20 years from now. Whether better or worse remains to be seen.

What would failure look like in a collapsing intellectual system? The complaints about the declining quality of grant and manuscript reviews may well be indicative of a general decline in the quality of intellectual discourse. As the growing profession attracts a larger proportion of careerists compared to the truly curious and as the competition for academic jobs and funding becomes keener, discussion among the practitioners naturally shifts from science toward politics. That will probably discourage participation by the relatively small subset of individuals who are driven by curiosity and who historically have contributed most of the major advances of basic science. Given the currently high levels of prestige and remuneration available to scientific researchers in academia and industry, it won’t be difficult to fill those places with more careerists, but this would further accelerate the dilution and decline of intellectual discourse. Manpower and expenditure could continue to rise but their efficiency in producing breakthrough advances might decline markedly. How would we know? It is impossible to know what has not yet been discovered. If discovery slows, we will simply assume that the remaining problems are harder than the ones that science has previously solved.

Rather than waiting for a visible collapse of academic research, societies need to listen to more subtle signs and symptoms. If scientific advances are, indeed, as important to future competitiveness as we believe, then the systems that build and sustain them warrant long-term strategizing by society. Hoping that the essentially medieval institutions of the university and peer-review can be scaled indefinitely to support such a growing enterprise is not a strategy.

“We have met the enemy and he is us.” Pogo cartoon strip by Walt Kelly, 1970