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Time to Say Goodbye to Our Heroes?

To increase the speed and impact of knowledge creation, the United States must radically restructure research funding and resources away from big names—and toward our biggest questions.

In 2018 I gave a presentation to the visiting committee that advises the dean and the director of the School of Earth and Space Exploration at Arizona State University. The committee sat around the director's polished table while I talked about how we were changing academic culture. "We think it's important that every person who wants to, gets to speak in meetings," I said, explaining that shouting is rare and considered extremely bad form.

A committee member named Max interjected, "But you'll never solve any real problems if everyone is always polite. The only way to really solve things is to let people bring it all, what they really think, and hash it out. In engineering I've seen it over and over. People have to stand up and bang their fists on the table and shout at each other until the real answer is found."

For a moment I was speechless; I had been running large research units for six or seven years, and I was leading a significant NASA mission with a team of hundreds of people. The many team-building and decisional processes embedded in these leadership positions had left me with a clear sense of what a good team was, and it had never occurred to me that a person could think that shouting was a better process. I countered that shy people or junior people were unlikely to speak up, even if they knew the answer. Pounding on the table would silence them, rather than eliciting more opinions.

"But if people are saying what they really know and believe," Max replied, "there's going to be some heat to come with it."

How could he think pounding on the table was actually a way to solve big, complex problems, I wondered.

The heroes of science

Since that meeting I have often thought about what the culture of pounding on the table means for the social model of science and engineering that we practice. Willingness to shout, willingness to assert, willingness to theatrically dominate others—all are still considered a sign of thought leadership in many scientific fields. But I have come to see it as a symptom of a much larger phenomenon that I call the "hero model" of science and engineering, which influences everything from who becomes a professor—and who gets harassed—to how we invent and what we discover.

This hero model describes the structure underlying most of the research done in the United States. In most academic institutions, the leading scholar in a given area of research is the acknowledged head of that group and has ownership of a pyramid of resources dedicated to his or her topic. These resources might include other professorships; staff, students, and their instructors; and curricula, buildings, and budgets. Thus a pyramid of resources is tied not to a topic but to an individual.

These heroes' pyramids are the building blocks of a much larger traditional academic and research structure in the United States that culminates in the $40 billion university knowledge creation enterprise. Heroes are the recipients of most US academic science funding; they are also seen as the moral leadership of their universities and even society at large. They are allowed extra-large voices on topics as varied as what knowledge should be created, how it should be funded, and how it should be adopted and regulated by society. Heroes advise presidents, talk to *60 Minutes*

about the ethical use of gene editing technologies, and are often given sole credit for the extraordinary technological transformations of the last 75 years.

But to deal with the human and environmental urgencies of the next 75 years, we need a structure that can create knowledge where we need it and enable faster adoption of innovations. This revised structure must enable broader participation on every axis, including gender, socioeconomic background, race, nationality—and across disciplines. Now is the moment to reimagine research—for the greatest use of resources, the greatest use of all human minds, and the greatest progress into the most positive possible future.

To achieve these objectives, we need to understand that centuries of near-exclusive use of the hero model has driven away talent, squandered energy on empty disciplinary and cross-disciplinary competition, and allocated precious resources to the pursuit of fame. And as our labs have focused on incremental gains in knowledge, we've largely consigned the existential questions about how we can navigate toward a shared future to science fiction writers, not scientists—while failing to explicitly train scientists to think of the larger meanings and directions of their work.

It's worth asking whether the hero model is a good thing for taxpayers to underwrite. Should so much of our spending still be tied up in these structures? Vannevar Bush, the postwar architect of US science policy, posed in his 1945 *Science, the Endless Frontier* an image of a government-led and funded research machine for fundamental discoveries. The report endorsed significant support for the experts and their pyramids. Bush and his committee envisioned a nation in which young people had open-door opportunities to rise in research, no matter the means or attitude of their family. What Bush and committee did not anticipate was the way the model would severely limit both research progress and training for early-career scientists.

Today's circumstances require optimizing the use of national funds, driving more directly toward key outcomes, and focusing scientists' attention on bigger existential questions. Breaking out of the old individualistic model opens up a new horizon, enabling greater and faster knowledge creation as well as radically more effective ways of educating students. This approach has been our aspiration at Arizona State University's Interplanetary Initiative, where we're exploring a new model of teams following "big questions."

Over the next century, we must create structures and incentives that support teams, knowledge goals, and societal outcomes rather than bolstering individual researchers themselves. And whether or not pounding on the table demonstrates that one's own answer is the correct one, the collective future of humankind requires that we hear all the voices at the table, not just the loudest.

Reorienting our focus from the hero model's "big people" to the consideration of big questions will address many of the challenges plaguing universities today: incremental, derivative, low-risk science; faltering funding; relentless focus on quantity of publication; irreproducible research; ongoing complaints of harassment; lack of diversity; an atmosphere that leaves students struggling with mental health; and (despite enormous funding outlays) an inadequately trained workforce in the STEM fields of science, technology, engineering, and math.

Who exactly is the hero model for?

Leaving the hero model behind requires first grappling with why it feels so natural to most of us. Our research institutions have some of their roots in the early fourteenth-century writings of the Italian jurist Bartolus de Saxoferrato, who argued that academicians qualified as heroes under Roman law because they had endured three trials: during their schooling, examination by faculty, and public disputation (a formalized system of debate). Since then, universities have made progress by supporting scholars to become experts—think of the named chairs at historic European universities in particular, and the tradition of naming the entire research enterprise after its leader.

An expert is seen as someone who has consolidated knowledge in the service of society. In return, an expert is rewarded with both power and resources. This notion of heroic professors as part of the public good is so ingrained in the internal social contract of the university that it is rarely questioned. It's notable that even as the external social contract between universities and society has been scrutinized and questioned during the last decade, the role of principal investigators has largely escaped notice.

And although the professor-based research structure was intended to work in the service of society, the incentives for those professors changed long ago. By the end of the 1700s in German universities, argues historian William Clark, "the fame machine had taken control." The fame machine made notoriety, rather than society, the focus of a professor's work.

Today, professors still fiercely strive to keep their names prominent and protect the intellectual property of their specialization. And the more successful they are at appearing to be "thought leaders," the more they are rewarded, while their actual service to society garners them very little. As a result, competitiveness is now a universal, pervasive condition of academic research. Researchers compete for funding, for the best students, for the publications with the highest impact factors, for space in the university, for media coverage, and for prominent lectures and awards.

And as competition for research funding has increased, fame's value has only risen. Federal grant programs make

awards to fewer than 20% of applicants and recent PhDs do multiple postdoctoral fellowships to be competitive for a permanent academic position. Fame is one of the few things that can assure higher funding rates, more successful student placements, and the invitations to write and speak that further perpetuate one's reputation.

As the California Institute of Technology physicist David Goodstein has argued, science used to be limited by the scientists' imaginations, but now it is limited by resources: funding and positions. This climate of competition incentivizes decidedly unheroic behavior by principal investigators. In a study of 51 research scientists, University of Minnesota professor Melissa S. Anderson and her colleagues found that scientists were doing strategic game-playing to entice competitors into dead ends of inquiry, failing to give credit to others, and pushing incomplete or preliminary publication in the pursuit of obtaining a higher number of papers.

What this behavior means for the society that underwrites these pyramids of resources is not only that money is wasted on bad research, but research progress is often confined to the small strips of real estate between the pyramids. Principal investigators assign their grad students to work on a small question adjacent to their pyramid, perhaps by applying a familiar technique to a new material. By design, this leads to incremental progress—which explains why corporations are often frustrated with academic partners who often are not trained to steer directly toward outcomes.

In some cases, of course, such meandering, incremental research yields results. As the biologist E. O. Wilson commented about his own exploratory scientific method: "When searching for a new phenomenon, try serendipity. Use precise but rough and easily repeated experiments to obtain some result or other, whether expected or not. The primary goal is to find previous unknown phenomena.… The best result of serendipity is surprise."

Curiosity-driven research is known to bring such surprises and discoveries, but there is no reason to think that research directed specifically at a big question on the edge of our comprehension would be less likely to yield serendipity. And in the long run, a more focused orientation would have the benefit of driving the research enterprise toward higher impact discoveries.

The hero and students

Students are doubly oppressed by the hero model: they are subject to the insular rules of their advisor's resource pyramid and they must compete with each other to become heroes themselves to attain tenure-track positions. To succeed, students must navigate an internal team culture and structure that is often opaque to outsiders, where bullying and harassment can proliferate. Even without such explicit abuse, students can be left on their own for years, leaving some to master the culture and thrive while others fall away in varying states of discouragement or bitterness. The culture further reveals itself in the way principal investigators wield possessive pronouns and proper nouns: "My" student, "my" lab, "my" team, and "The Smith lab" rather than "The Lab for Human Genome Research." Why do we need to personally own it all?

Personality-dependent careers are notoriously fragile: graduate students' intellectual and career progress is both inspired and profoundly limited by the knowledge, process, and kindness of their advisors. And tragically, the many postdocs who are unable to get tenure-track academic positions often believe they are failures—even though their eventual paths in government, industry, or elsewhere might in fact be far more valuable to our common future. By failing to prepare our students for productive lives outside of academia, our universities have reneged on their part of the social contract.

It's time for us to reexamine what our research structure is doing to higher education, our students, and the societies and economies in which we live—and to use that examination as an inspiration to create more equitable structures in which new people can be trained. This revised research structure should result in career success based more on a scientist's contributions than their charisma.

Although I am arguing that the hero model needs to be replaced, I am not advocating for doing away with expertise and deep disciplinary knowledge. The very concept of being an expert is a little-appreciated piece of human miraculousness: the long and winding path to inhabiting and assessing the far reaches of a field of knowledge produces a rare perspective on what knowing, itself, is. This position should not be accompanied, however, by freedom from the consequences for bad behavior. And if we want to broaden the knowledge of society, we must find ways to value the expertise of all—including the lay person, the postdoc, the uncharismatic, those who do not pound on tables. And for those of us now classified as heroes, breaking out of the role to do more socially engaged science can be a liberating experience—as I have been learning.

Replacing heroes with teams to pursue big questions

To reach higher research and educational goals, we need to remove the barriers between disciplines, thus enabling transformational rather than incremental improvements in knowledge. To do this, we should focus on key questions, building teams of people from many disciplines to answer them.

NASA uses its matrix organizational model in precisely this way to focus project teams on highly aspirational goals such as designing and building a spacecraft to go to Jupiter's icy moon Europa. These project teams contain many brilliant

individuals, and team cultures vary. Some teams have biased and exclusionary cultures reminiscent of *The Right Stuff*, Tom Wolfe's book about hotshot test pilots and future astronauts. By contrast, other team cultures are deliberately egalitarian, reflecting the need to value and listen to every voice when scanning for fatal design flaws, for example. In NASA's high-risk research environment, much more so than in a university lab, interdisciplinary teams train themselves to listen omnivorously in order to reduce risks and reach their goals faster.

In some ways, NASA's matrix model and the Interplanetary Initiative's model of asking big questions resemble proposals from the 1990s, when scientist Michael Gibbons and his colleagues called for a transdisciplinary, team-based, societally engaged research model that they dubbed "Mode 2" ("Mode 1" being the traditional, siloed disciplinary model of basic research). Although both the NASA model and the Interplanetary Initiative model make use of transdisciplinary teams to solve complex problems, the difference is that teams in our big questions model are built around a goal rather than a leader. I believe that this reorientation, which creates a uniquely deliberative team culture, is better at uncovering new ideas and making faster progress.

The best versions of the team model contain competition, but it is competition done right. That is, teams cooperate for outcomes while competing with other teams for funding and resources. Progress is monitored not on an individual level but on a team level.

In this, the teams bring people together to become more than a collection of individuals. When united in search of an external goal, team members strive to support each other rather than compete. And one of the peculiar joys of working in a high-functioning team is that it creates a richer and happier life for each member. Thus, this team structure can accomplish many social goals such as equal inclusion of diverse voices, support and growth opportunities for young investigators, and a reduction in harassment. These social goals seem out of reach or often are dismissed as irrelevant in the hero model.

Identifying big questions

Before we begin building teams, we first identify big questions that need to be answered to make progress in a broad area of endeavor. At the Interplanetary Initiative, we start the process by bringing together 20–60 interested people to brainstorm.

But these are not just any people; we like to invite lots of different people. In 2017, our first year, we had deans, faculty, staff, graduate and undergraduate students, people from local corporations, service members from the Air Force, and private citizens from our community. All participated and many persisted fruitfully on the teams throughout the year. Since that first successful experiment, the mantra of "everyone is invited, all the time," has become embedded in our process—reflecting a conviction that everyone is an expert in what they view as important in society, and that drawing in their many perspectives makes us stronger.

The purpose of the convening is to find the sorts of questions that can frame big areas of inquiry. When we talked about exploring the future of human space exploration, for example, people volunteered their ideas of essential questions for a positive human space future, including: What social and political norms are necessary for lunar or Martian settlements founded by different nations or private entities? How can communications and location services be created according to a common standard for the Moon? How do we create more effective human–robot teams?

As the session goes on, we discourage the kinds of questions that reflect incremental thinking, and instead focus the group on purposefully asking big, critical questions. The goal questions are of vital importance and are the foundation of all the work that comes after.

Once we have a list of questions written on a whiteboard, we begin to discuss their merits one by one. Do any of the experts in the room think it's misstated, or already known? How vital is its answer, really? We end up with a collection of questions that have survived the process. By the time we've discussed them all, each person in the room has privately calculated that some questions are important and a few are an embarrassment. Interestingly, by this point there is not complete agreement on which questions are which, and thus there is no reason to talk about whether any might be dumb questions. For one thing, a question that seems "dumb" could well reflect contrarian thinking that might prove productive. When we are finished discussing all of the questions, we vote, with each person getting two or three votes. At the end, we have a short list of top questions to consider.

Creating interdisciplinary teams

Once we've determined the questions, we set about deliberately building interdisciplinary teams. We start by inviting participants to volunteer into groups around the highest-voted goal questions. Each group is given an hour to decide on some concrete outcomes that would advance progress on their question and that could be accomplished with a year's work. Each team determines what disciplines they will need to work with to reach their goals.

All too often interdisciplinarity is a synonym for moving our disciplinary mountains closer together; or for hiring people who themselves are fluent in more than one discipline; or, in the third and perhaps saddest model, by taking a person from one discipline and assigning them to a different established disciplinary team, where they float as a kind of mascot.

In assembling our teams, we seek an interdisciplinarity that is egalitarian and question-driven, but still very much

composed of experts in the traditional sense. You might think of the NASA project team, with engineers of various kinds, project managers, scientists, financial controllers, schedulers, graphic artists, and media managers. Each person's contribution is valued because each person's discipline is required for success in meeting the common goal.

Thus, interdisciplinarity is baked into these teams so that they not only produce results but also answer the goal question. Members are judged not by the usual outcomes—papers, grants, talks—although these do have their place, but by how well team members have addressed the central problem. This reward structure is absolutely crucial: interdisciplinarity needs to be owned at the highest level of the research organization and the culture must reward team outcomes rather than individuals.

At the end of the hour, each team has a goal question and a list of outcomes, which might include a white paper for a governmental oversight group, a prototype, or an event, along with the standard papers and talks. Then they outline other disciplines they need to reach their goal, and a facilitator helps them choose a leader.

Over the next two weeks, it's the team leader's job to make sure their team creates milestones for their year of work, drafts a budget to cover their needs, and finds the names of people in the necessary disciplines. We have found that if the team returns with the budget and milestones, they indeed have a reasonably effective leader, which is a requirement for progress. Currently, we select faculty members as leaders for the simple reason that they are already paid to do research and they are able to take on the fiscal responsibility of the seed money.

We then fund the teams with seed money, ranging from $5,000 to $60,000, with an average amount of $25,000. (One large pilot was supported by philanthropic funding.) Seed money can cover expenses such as some staff or student salary; undergraduate interns; and costs of materials, travel, and events. Though these funds will not usually cover even a graduate student's full salary, we have found that the money—along with the pure pleasure of being part of a team going after a big goal—has kept almost all the teams going all year.

The big questions model, which at first seemed risky, has proven itself extraordinarily effective. Of the 25 pilots we've selected over the past 4 years, 13 have launched successfully to additional funding or completion, 9 are continuing in our program on a mixture of seed and external funding, and 3 failed. This year alone we have 120 active team members and 20 outside partners.

We have lost no momentum in output. Our first peer-reviewed paper appeared only four months after our first pilot selection. What's more, we've increased the overall speed of innovation by moving more directly toward significant goals, including using our seed funding to build capacity that has allowed our projects to generate eight times the seed investments in follow-on federal and private grants and contracts.

One compelling measure of the projects' success is that our teams have pursued goals that do not fit neatly in the usual research enterprise, but they have leveraged their seed money to produce proof-of-concepts that enabled them to get conventional funding. One of many examples is Port of Mars, a multiplayer game designed by sociologists to gather data on human behavior in potential settlements on Mars; it recently received funding from the National Science Foundation. Another example is a pilot study of a speculative method to taxonomize and then design responsive space missions so that they can be repurposed and redirected after launch; this project recently received Department of Defense funding.

A transformative culture

Over the years I've thought about what makes our team process more effective—and more enjoyable—than the academic research model I was trained in. While the whole process contains purposeful changes from the standard model, I want to highlight two elements of the special sauce: project management and culture. These two components are where we leave behind the inward-looking hindrances of the hero model to embrace our larger ambition of serving society.

I've mentioned that each team in our process chooses a research leader, but that person is almost never an expert in team management, project scheduling, risk assessment, or financial management. (How many faculty are?) To remedy this missing expertise, we give each team a project manager who can provide the needed schedule, risk analysis, and budget framework, as well as performing the human resources functions that create standards of culture and process.

From the point of view of the research institution and funders, placing each team under project management protects the investment. Importantly, it also socializes the team for partnership with private organizations that expect budgets and schedules to be met. Furthermore, including a project manager keeps the team focused not only on answering the research question but also on the larger goal of delivering knowledge to society.

Within these professionally managed interdisciplinary teams, culture and team norms are discussed, and when the teams are willing, created. There is a pervasive idea in the pound-the-table pyramid that mannerliness is a sign of weakness, and only the weak require a discussion of culture. Culture, however, is elemental to creating speed and success for teams. Some NASA program directors and administrators have told me they consider team culture a main indicator of future success in mission teams, observing that an inclusive, listening team will overcome adversity and reach its goals

whereas a secretive and ego-driven team will collapse under stress. Thus at NASA, effective team cultures are rewarded with hundreds of millions of dollars in funding. In this culture each person is valued according to their contribution rather than title. Being listened to, previously a hallmark and benefit only of being the hero, becomes the prerogative of every team member.

Project managers consciously shape team cultures in other ways. They encourage teams to solve challenges by creating a culture of "Yes, and…" rather than the academic reflex of "But…"—these teams achieve more and support their junior members to greater successes. In such teams, members form relationships that lead to trust, open discussion, and mentorship. Senior people connect with junior ones, enhancing, broadening, and cross-pollinating each other's networks. More mentors means better outcomes for students, who then have more options for a good fit with a mentor. A wider mentor pool also adds more perspectives to help trainees figure out career paths and research development.

After years of thinking about Max's comment about pounding on the table, I have a rejoinder: A culture of listening is transforming our work in every way: helping us meet our practical and social goals through interdisciplinary work as well as reengaging us in the social contract of educating students. There is simply no comparison. And there is no going back.

In the future, restructuring the US research enterprise to enable such teamwork could help the nation reach larger goals of transforming the pace of innovation and education. In my years of experimental research, I've observed how opening up our process to community observation, questions, and steering can strengthen the connections between the university and society. With this restructured model focused on rapid, directed progress not only on technological innovation alone but also on society's deepest commitments, it would be foolish to continue to spend all of our research dollars on the traditional model envisioned and instituted by Vannevar Bush more than 75 years ago.

Of course, I understand quite well the difficulties of leaving behind our old models of research. I, too, was trained in the heroic ideal. And back in January 2017, as we began our very first brainstorming session, I felt anxious. I stood at the front of the room welcoming people in, a little like the host at a party with a risky guest list of 50 and too few RSVPs. As each person came through the door, I felt a little lighter and the room began to feel different, too. When we started the process of determining our goal questions, the room changed again. People contributed ideas. And they were not just the usual vocal participants, such as the deans and senior faculty, but also undergraduates and our friends from the town. Soon we had dozens of relevant, aspirational, and important research goals. I had an unfamiliar feeling of having shed an academic persona and come together with a shared feeling of purpose simply as one inspired human being among others.

Over these years of experimentation with a team-based, externally focused research paradigm, I've felt my relationship to the scientific work I've been doing for the past two decades transform and accelerate. I used to love tackling the next challenge from my own pyramid of research resources. Now that feels more like a hobby and working with teams to pursue bigger goals has far deeper meaning. Sharing the excitement is infectious, and sharing the responsibility is relaxing. I feel this most of all with the Psyche mission, where a team of 800 people is preparing to send a robotic spacecraft to orbit an asteroid and learn about the first metallic solar system object humans have ever visited. I'm attempting be a servant leader, and my world feels more rational and meaningful as a result.

As scientists, we must ask ourselves whether we are solving the biggest and most urgent problems, and whether we are lifting up our colleagues and the next generation to do the same. The responsibility and the power to create change lies in our hands. We can imagine how to do research that more rapidly and effectively enables a more hopeful future—and by doing so, we can reimagine ourselves and our society.

Lindy Elkins-Tanton *is the vice president of the ASU Interplanetary Initiative, and she is the principal investigator of the Psyche mission, selected in 2017 as the 14th in NASA's Discovery Program.*

RECOMMENDED READING

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