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Humanizing Science and Engineering for the Twenty-First Century

Science cannot live by and unto itself alone: forward-thinking science and technology policy depends on better integrating the humanities, arts, and social sciences.

Dr. Nettrice Gaskins is a widely recognized African American digital artist who creates works that combine images of individuals with an artificial intelligence (AI) application that synthesizes patterns. When her larger-than-life portraits were displayed in the Smithsonian Institution's "FUTURES" exhibit in 2021, viewers saw familiar faces rendered with finely grained and sometimes disorienting details, inviting them to consider moral and ethical questions about future uses of AI. By fusing artistic exploration with moral and political reflection on technology, Gaskins's work exemplifies the creative possibilities that lie at the intersection of science, engineering, and art.

We think work such as Gaskins's—which integrates science, technology, engineering, and mathematics (STEM) with the humanities, arts, and social sciences (HASS)—is an important and long-overlooked element that should be included in forward-thinking science policy. More than 75 years ago, Vannevar Bush's report for President Roosevelt, *Science, the Endless Frontier*, focused on spurring research and training in the physical and biological sciences. Yet "it would be folly," Bush warned, "to set up a program under which research in the natural sciences and medicine was expanded at the cost of the social sciences, humanities, and other studies so essential to national well-being." As another report that Bush references put it: "Science cannot live by and unto itself alone."

That warning was not heeded. STEM fields have long insulated themselves from the arts and humanities in problem discovery, in the design and implementation of solutions, and even in the public policies and communication strategies needed to ensure optimal outcomes. In Bush's vision, scientific progress was essential not just for improving public health, jobs, and living standards, but also for advancing what he termed "cultural progress." All of this requires careful attention to the interrelations among science, technology, and society—interrelations that are not fully illuminated with a STEM lens alone. Indeed, STEM and HASS domains intersect in the challenges and threats people face every day, from poverty and energy production to climate change, food and water safety, and national security.

Solving such complex problems is never a purely technical or scientific matter. When science or technology advances, insights and innovations must be carefully communicated to policymakers and the public. Moreover, scientists, engineers, and technologists must draw on subject matter expertise in other domains to understand the full magnitude of the problems they seek to solve. And interdisciplinary awareness is essential to ensure that taxpayer-funded policy and research are efficient and equitable and are accountable to citizens at large—including members of traditionally marginalized communities.

Bridging the STEM-HASS divide is a crucial task for the coming decades of science and technology policy. Society needs robust institutional frameworks for equipping STEM practitioners with a humanistic lens to elucidate problems, imagine solutions, and craft interventions. As a first step, colleges and universities must better integrate STEM and HASS in their curricula. While this is a daunting challenge, a wide range of efforts over the last two decades helps point the way forward.

Methods for integrating the humanities

Technological universities offer a particularly fruitful institutional climate for imagining new forms of HASS and STEM integration. At our own institution, the Georgia Institute of Technology, HASS faculty recently published a collection, *Humanistic Perspectives in a Technological World* (2021), featuring dozens of case studies illustrating how HASS and STEM can be brought together in research, scholarship, teaching, and community projects.

One approach is to focus on the design of individual courses, with HASS faculty members purposefully collaborating with STEM colleagues. A two-semester junior capstone sequence at Georgia Tech is cotaught by a subject matter specialist in computer science and a technical writing faculty member. This arrangement not only sharpens students' communication skills; it also inspires them to situate their scientific work in a larger context—for example, by considering how it will be received in a field rife with gender and racial bias. Another example is project EarSketch, used by one million students worldwide, which integrates coding education with music composition and has helped underrepresented students learn to code. Project Code Crafters merges the creativity of computing and quilting for diverse adult audiences, building knowledge in how to broaden public engagement in computational thinking. And DramaTech, Georgia Tech's student-run theater troupe, regularly infuses theatrical performances with elements of digital media, as when it staged a dramatic adaptation of Haruki Murakami's short story collection *after the quake*, employing a motion-sensing device to track an actor's gestures to amplify emotions.

Another approach is to restructure entire degree programs. Georgia Tech's undergraduate major in computational media, for example, is collaboratively administered by faculty in computing and the humanities. Similarly, a master of science in human-computer interaction program draws on faculty in computing, design, humanities, and the natural sciences. Rather than being housed in a single department, both programs have interdisciplinarity built in as a basic feature of institutional design. The result is that students are trained to think across a range of disciplines and to leverage their exposure to diverse methodologies, to better understand and tackle complex problems.

These initiatives are a small part of a larger interdisciplinary transformation. Georgia Tech is part of a systematic, nationwide effort described in the 2018 National Academies of Sciences, Engineering, and Medicine consensus report, *The Integration of the Humanities and Arts with Sciences, Engineering, and Medicine in Higher Education: Branches from the Same Tree.* As the report documents, integrating the humanities and arts in STEM and medical education is linked to numerous positive learning outcomes, including increased skills in communication, critical thinking, and teamwork; improved visuospatial reasoning and overall content mastery; increases in empathy and resilience; and improved motivation, enjoyment of learning, retention, and graduation rates. The report also presents evidence that STEM-HASS integration positively affects the recruitment, learning, and retention of women and individuals from underrepresented minority populations in science and engineering.

The *Branches from the Same Tree* report notes that deep and intentional integration of disciplines is essential to preparing "for the challenges and opportunities presented by work, life, and citizenship in the twenty-first century." It thus takes aim at a development Bush may well have foreseen as early as 1945: higher education's "increasing specialization" and discipline-based "fragmentation of curricula," which prevent students from seeing all human knowledge as "fundamentally connected."

Training better doctors

It is in medical education that this paradigm shift has had some of its most enthusiastic early adopters. Over the last 22 years, the number of health humanities programs in the United States has ballooned from 12 to 140, and in 2000 the *Journal of the Medical Humanities* was founded as a companion publication to the *Journal of Medical Ethics*. The Association of American Medical Colleges recently evaluated these efforts in *The Fundamental Role of the Arts and Humanities in Medical Education* (FRAHME), highlighting four "functions" of humanities and arts integration: mastering skills, perspective-taking, personal insight, and social advocacy or sociocultural critique and change.

A central component of the FRAHME report is what its authors call the "Prism Model," in which

> each function is conceptualized as a lens in a prism that can help educators approach any domain they wish to teach (e.g., communication, empathy) in multiple ways, depending on which function is emphasized. Each function offers a different yet interrelated way of seeing arts and humanities teaching. The four functions are most powerful when used in combination, as a way to more fully recognize all pedagogical possibilities for arts- and humanities-based teaching in medical education.

Recent examples from medical schools of such measurably successful integration range from individual class sessions and learning activities to longitudinal tracks and programs.

At the level of individual learning activities, studies show that even brief reflective pieces of creative writing have helped teach medical practitioners and students to develop humanistic and ethical understanding of patient care and to view themselves as healers, even when they work in highly systematized environments. In addition to reflective writing, the practice of close reading and application of narrative theory to clinical texts (such as medical charts and patient interviews)

can significantly enrich conventional medical routines of diagnosing patients' conditions. Now generally recognized as central to developing more trusting and efficacious patient-physician relationships, "narrative medicine" makes use of script writing, performance of medical stories, documentary films, dance, and jazz improvisation.

Intentionally integrating HASS methods and skills over several years of training leads to deeper engagement and sometimes to social advocacy. The Johns Hopkins University School of Medicine, for example, offers a scholarly concentration in the history of medicine as part of its independent mentored research program during the first two years of study, adding a 16-month humanistic learning experience to students' basic science and clinical research requirements. In the concentration, students work with assigned faculty historian mentors to learn literature-based, archive-based, and oral-historical research theories and methods. They apply these to fieldwork and narratives across historical periods, leading to publications geared toward clinical, historical, public health, and popular audiences. Graduates of the program become medical doctors with a deep appreciation of history as an effective mode of humanistic engagement in clinical practice.

For example, students in the program compared anti-Asian sentiments during the COVID-19 pandemic with xenophobia during a bubonic plague outbreak in Cape Town, South Africa, in 1901 to explore the potential dangers of discriminatory health policy responses. By researching the Cape Town plague, they were able to understand how it gave colonial authorities a pretext to forcibly remove most of the city's Black population from neighborhoods, laying the foundation for apartheid. Grounded in this new historical perspective, students in the program publicly advocated against the stigma and racism that have sometimes influenced the pandemic response and policy.

The full Prism Model would require integrating the four basic functions at all levels of training, from individual assignments and courses up through the curricular structure of whole degree programs. Some medical schools are well on their way to such deep integration. Florida International University's Herbert Wertheim College of Medicine, for example, uses art analysis during museum tours as a practice analogous to detailed patient diagnosis.

Early-stage and wide-ranging integration

One lesson to be drawn from all this work is the importance of incorporating HASS into STEM as early as possible. Unfortunately, apart from notable early upstream inclusion of economics, integrating HASS later is the norm; these disciplines are often considered relevant only at a late stage in conveying scientific results and technological innovations to the public, not in early-stage planning, design, or research and development. To take just one example, social scientists have found that, in European energy research and policymaking, HASS concerns are effectively treated as project "add-ons" rather than as equal partners in the production of evidence. But excluding HASS disciplines and methodologies can lead to results that are ahistorical and future-centric and emphasize quantitative methods while treating society as passive. The exclusion is also self-reinforcing, introducing a path dependency that affects future funding decisions and the overall trajectory of the field.

Other studies have demonstrated what stands to be gained from more robust HASS and STEM integration. A recent marine science study in Scotland, for instance, showed how collaboration across HASS and STEM led to resolution of a seemingly intractable dispute between government conservation scientists and an economically fragile community in the Outer Hebrides. Government researchers initially did not recognize the political nature of a dispute over preservation of biological diversity in a proposed marine conservation area. But when collaboration among a researcher, an artist, and community stakeholders facilitated a participatory mapping process, they were able to see the relationship between biological diversity protection and sociocultural heritage and knowledge. The outcome was the creation of the Sea Stories' online, interactive map representing the narratives and values of the community in the marine context. The map came to be used by policymakers and community partners alike as they created a collective co-management process for the area. Initiating partnerships across disparate fields and actors facilitates the meaningful coproduction of scientific knowledge, which can strengthen the relationship between science and society and propel cultural change. It may also result in tangible policy outcomes—in this case, improving the planning and management of a protected marine environment.

Another recent National Academies report, *Integrating Social and Behavioral Sciences Within the Weather Enterprise* (2018), provides examples of successful HASS-STEM integration while recommending further opportunities for collaboration. Today, weather forecasts are often seen as simply projections of future atmospheric conditions, but to apply them in ways that prevent damage and deaths as a result of severe weather requires a deeper understanding of the social and behavioral factors involved. Beyond meteorology, then, combining interdisciplinary insights can generate systems and products that more holistically and accurately account for people's cognitive processes, behavior, and interpretation while optimizing public safety, which is especially useful during severe weather warnings. Understanding how weather forecasters make decisions, and how laypeople interpret what forecasters say, is less a meteorological concern than one for the social sciences.

Indeed, as scholar Victoria Martin has written, "many of the environmental challenges we face are, fundamentally, human problems" and will therefore benefit from the knowledge, training, and experience embedded in the social sciences. This can be seen across disparate fields. Scholars have explained, for example, that transitions from fossil energy to renewable forms are "fundamentally socio-technical (meaning that society

and technology affect each other and co-evolve) in both their underlying processes and outcomes." In other words, solving such challenges requires not only a knowledge of electrons, materials, and transmission rates, but also a sense of how human concerns, social values, and aesthetics may come to bear on the issues. Incorporation of social science expertise ensures that natural science studies build on appropriate prior scholarship and apply robust methods—from research design to data collection, analysis, and reporting of results—to produce sound knowledge that does not waste resources.

Bringing the two cultures together

Failing to take advantage of the types of knowledge that the humanities and social sciences offer is already yielding an opportunity cost for the STEM disciplines themselves. Consider, for example, the relatively new field of "science of science policy" (SOSP), kindled in the 2000s and championed by the former director of the White House Office of Science and Technology Policy, John Marburger. The purpose of SOSP is to improve decisionmaking on investments in research and development and build talent in science and engineering fields. It is a systematic integration of scientific knowledge, analytical capacity (from the social sciences), and policy processes with the purpose of improving scientific output, economic growth, and social well-being.

Marburger and others called for the social sciences to take on greater responsibility in the process, particularly in developing high-quality frameworks, tools, and data, a corps of trained professionals in the science of science policy, and a network of convenings fostering engagement that improves policy. So far, much of the SOSP work has been quantitative, but early engagement of scholars in the humanities and social sciences could elevate a more robust science policy.

Interdisciplinary approaches could yield benefits including sharper assessments of policy impacts, tailored communication of policy impacts to affected groups, improved policy design, and methodologies grounded in a broader scope of disciplines. The question of whether science policy "works" is not only a question of whether the right number of widgets are produced or whether projections turned out to be correct, but rather whether the policy meets the greater aspirations of the society in which it is embedded. For that sort of analysis, the humanities provide a set of lenses that are essential for charting a shared future.

Crucially, enhanced integration between the humanities and the natural science disciplines could enable a more ambitious vision for achieving Vannevar Bush's goals for scientific and cultural progress. Breakthroughs in science, arts, and humanities will remain dormant unless these fields learn to cultivate a diverse and inclusive talent pool and generate socially relevant research that informs policy. World-renowned cellist Yo-Yo Ma said it best: "Culture turns 'the other' into 'us.'" As he explained:

> From the golden rule to the iconic "Ode to Joy" from Beethoven's Ninth Symphony, a symbol of freedom and unity around the world, to $E=mc^2$, the radical formula that changed how we understand the universe, these words, sounds, and codes help us speak a common language and agree on shared values. They give us a foundation for trust…. It's not enough to outsource culture to the artists and musicians, and receive it as a passive audience. We must engage the full spectrum of human understanding, and every one of us needs to participate in strengthening our cultural resources, all the time—to generate trust and understanding by pursuing basic scientific research, playing music together, or simply looking at the stars. We need to put culture first, because it is the only way to make sure that the decisions we make as a global society are actually good for humanity.

Integrating cultural and socially relevant values and approaches into science and technology policy and research will enhance progress in all these disciplines.

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RECOMMENDED READING

Rita Charon, "At the Membranes of Care: Stories in Narrative Medicine," *Academic Medicine* 87, no. 3 (2012): 342–347.

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National Academies of Sciences, Engineering, and Medicine, *The Integration of the Humanities and Arts with Sciences, Engineering, and Medicine in Higher Education: Branches from the Same Tree* (Washington, DC: The National Academies Press, 2018).

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