Supporting Scientific Citizens

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What do nuclear fusion power plants, artificial intelligence, hydrogen infrastructure, and drinking water recycled from human waste have in common? Aside from being featured in this edition of *Issues*, they all require intense public engagement to choose among technological tradeoffs, safety profiles, and economic configurations. Reaching these understandings requires researchers, engineers, and decisionmakers who are adept at working with the public. It also requires citizens who want to engage with such questions and can articulate what they want from science and technology.

This issue offers a glimpse into what these future collaborations might look like. To train engineers with the "deep appreciation of the social, cultural, and ethical priorities and implications of the technological solutions engineers are tasked with designing and deploying," University of Michigan nuclear engineer Aditi Verma and coauthors Katie Snyder and Shanna Daly asked their first-year engineering students to codesign nuclear power plants in collaboration with local community members. Although traditional nuclear engineering classes avoid "getting messy," Verma and colleagues wanted students to engage honestly with the uncertainties of the profession. In the process of working with communities, the students' vocabulary changed; they spoke of trust, respect, and "love" for community—even when considering deep geological waste repositories.

To previous generations, the idea that nuclear engineers would be comfortable applying words like "love" to their work is somewhat mind-blowing. Today's nuclear power plants were designed and sited with minimal citizen involvement, and feelings would have just gotten in the way. The same goes for the rest of the energy system—the electrical grid and global web of tankers, pipelines, coal mines, and oil wells—built to varying government, industry, and economic imperatives. But to achieve larger goals of decarbonizing energy systems and becoming a more just society, the energy transition needs deep citizen input. In part, this is because the trust between communities and power plant operators must be rebuilt to reflect today's values of egalitarianism and transparency. It's also a practical matter: the deployment of next-generation nuclear technologies requires social support.

And this process is necessary well beyond nuclear power; technologies as disparate as AI and sewage treatment also need citizen input to develop public trust and balance tradeoffs that meet larger social goals such as reliable information and drinkable water.

Many communities in the United States—transcending political and geographic barriers—are eager to participate in sociotechnical transformation. When the National Science Foundation announced the Regional Innovation Engines program to spur innovation ecosystems across the United States, they received 679 submissions from 520 organizations—for just 10 slots. Similarly, 378 communities applied to the US Department of Commerce's solicitation for its Regional Technology and Innovation Hubs competition. And 79 applications were submitted for inclusion in the Department of Energy's Regional Clean Hydrogen Hubs program to develop hydrogen energy infrastructure—exceeding the funding provided for the program by approximately nine times.

The scientific enterprise has been slow to recognize that the characteristics of emerging technologies—and public desire to participate in their deployment—require a shift in emphasis from discovery and technical innovation to social transformation. The top-down

innovations of the postwar period prioritized skilled researchers and engineers, rather than social scientists and public participation. These priorities remain baked into federal funding. Of the nearly 83,000 STEM graduate students the federal government supported in 2021, only 6,271 were social scientists. Those differences in funding mean social scientists are more likely to graduate with debt than other scientists.

Similarly, the enterprise successfully raised the number of postsecondary STEM graduates at all levels by a third between 2012 and 2021—no small feat. But meanwhile K–12 scores in math and science drifted downward, with a growing gap between the highest and lowest scores. The enterprise is investing in the scientific minds required for previous technological revolutions but not yet in the broad base of scientific citizens needed for the future.

It's helpful to look back at the period after the Civil War, when agriculture—particularly, new crops and new methods of farming—was something like semiconductors today: a route to national security and regional economic transformation. Within a few decades, after the creation of the US Department of Agriculture (USDA), the establishment of land grant universities, and the founding of historically black colleges and universities, it became clear that this wasn't a technocratic process, but one that required that every farmer to become a science-based, industrially attuned, constantly innovating participant.

The next step was a system of hundreds of local, semiautonomous agricultural research and demonstration stations, funded by the Hatch Act of 1887. The map of these stations from 1900 resembles that of the hopeful candidates for today's innovation hubs. But still more outreach was needed to get farmers involved, so county extension agents were enlisted to spread information personally.

Finally, "corn-growing clubs," an innovation from Ohio, gave boys seed corn and awarded prizes to those who produced the highest yield. Girls joined "tomato clubs," where they canned tomatoes with the latest scientific guidance. As these clubs became USDA's 4-H program, they connected the universities and experiment stations to kids, teaching them record keeping, data gathering, and reliance on expert knowledge.

In the early days, the clubs were a trick to get to their parents. "The farmers were reached through their children, and the interest thus aroused will be handed to their children's children," a USDA official wrote in 1905. But it was the "children's children" who drove an agricultural revolution through decades of continuous innovation in agriculture as farmers incorporated mechanization, hybrid seed, fertilizer, pest control, and irrigation, not to mention financial incentives like crop subsidies.

This earlier construction of the scientific enterprise committed significant resources not only to research, but directly to community problem-solving, outreach, knowledge generation, and dissemination. More importantly, the agricultural stations, extension service, and 4-H enabled citizens to gather data and employ scientific insights in their daily lives—making them participants and beneficiaries in sweeping social and technological changes. (Full disclosure: I was a 4-H kid, furiously competing for blue ribbons in the County Calf Scramble and science-informed muffin-baking. But I'm not advocating for 4-H, so much as a scientific enterprise that deliberately and persistently engages with all of society, particularly young people.)

Another opportunity to engage might be found in reimagining citizen science as a platform to enable scientific citizens. Citizen science projects aim to engage the public in research—gathering data, sorting it, or decoding, say, protein folding. But these efforts have a tendency to employ citizens as helpers rather than full participants. In a 2024 report on federal prizes and citizen science, the White House Office of Science and Technology Policy mentioned that 46 out of 82 federal citizen science projects noted that getting citizens to hoover up data is "cost-effective."

Some projects, however, empower the public to gather data and use it to advocate for themselves and their communities. One example is the National Oceanic and Atmospheric Administration's campaign to engage cities in mapping urban heat islands, which helps communities execute a volunteer-led field campaign to document and understand the effects of heat on residents' lives. Participants then become invested in taking action.

As much as developing and deploying emerging technologies requires scientific citizens as active participants, with support these same technologies could enable and empower community decisionmaking by making it easy to collect data and use artificial intelligence and other resources now confined to researchers. For example, iNaturalist's smartphone app helps users identify and map the position of invasive plants, which is essential for finding strategies to control them. With its AI interface, the app gives users an immediate (though tentative) identification of plants and animals. Later, experts weigh in—taking advantage of the synergy between their knowledge and the efficiency of the platform.

In my community, where invasive plants are infiltrating sensitive wetlands, the app makes us better—better naturalists, better neighbors, better marsh stewards, and better all-around citizens. As the enterprise's mission shifts to support social transformation, it should search for deeper public engagement in these rarely recognized intersections of science and love.