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Educating Engineers for a New Nuclear Age

Radical designs for fission and fusion energy systems require engineers who are grounded in technical knowledge, adept at engaging communities in participatory design, and fluent in ethical, equity-centered communication.

Engineering education has long prioritized technical mastery above all else. And though such prioritization has equipped engineers with powerful analytical tools, this singular focus has left them unprepared to address some of the most pressing and complex challenges humanity faces. A more robust standard of engineering proficiency would include a deep appreciation of the social, cultural, and ethical priorities and implications of the technological solutions engineers are tasked with designing and deploying.

We are faculty in nuclear engineering (Verma), mechanical engineering (Daly), and technical communication (Snyder) at the College of Engineering at the University of Michigan. As researchers and educators, we are teaching our students the necessary skills and tools to collaborate on the design of nuclear facilities with communities from the start—rather than as an afterthought. Together with students, we are working to advance a new vision of what it means to be an ethically engaged engineer.

Our incoming engineering students already take this challenge to heart. On the one hand, they are eager to design solutions for the wicked, intractable problems across the built world—climate change and energy injustice and shortages of housing and food, for example. And they can see that they and their peers will need to craft excellent technological interventions in the coming decades if humans are to endure and thrive. On the other hand, our students are aware of the role the discipline of engineering has played in exacerbating the very problems engineers are tasked with solving—like climate change and the energy transition. They are attuned to the global scale of energy injustice, recognizing that minoritized and under-resourced communities are the most likely to bear the toxic consequences of open-pit mining, coal-fired power plants, and fracking—systems partly enabled and perpetuated by engineers. They desperately want to help address these injustices, but they see that engineering curricula are largely disengaged from peoples' lived experiences in vulnerable communities. What's more, they see that the engineering disciplines they are called to are uncritical of the outsized power and often harmful consequences of engineering work.

Nuclear communication

As faculty, we are acutely aware of the need to prepare engineers to work on the next generation of smaller nuclear facilities to reduce carbon emissions quickly. Fusion energy systems are being developed at a rapid pace for deployment as early as mid-century; many of these will likely be much smaller than today's gigawatt-scale fission facilities. New modular fission reactors (which produce up to 300 megawatts of energy) and microreactors (which produce between 1 and 20 megawatts of thermal energy) will soon be deployed, potentially at commercial scale in the 2030s. Though powerful enough to electrify small towns, these technologies are about the size of shipping containers—small enough that they could literally sit in someone's backyard. It is ethically and practically imperative that engineers collaborate with and understand the needs of the people who will live among these facilities.

Nuclear engineering has notably fallen short when it comes to engaging ethically with communities. Approaches to siting facilities have often ignored the rights, needs, and values of local communities and the land they inhabit. The operating assumption of the default approach—sometimes described as "decide, announce, defend"—is that engineering experts know best, and it is their prerogative to decide where and how facilities should be built. Having made these decisions, engineers need only explain and defend them before the public.

The results of such an approach have sometimes been tragic. On the front end of the nuclear fuel cycle, there are many abandoned and unremediated uranium mines on Navajo Nation lands in the southwestern United States, for example. Land, water, and air have been contaminated, affecting not only human health but also traditional ways of life and whole ecosystems. On the back end of the fuel cycle, failure to consult host communities while siting a nuclear waste repository at Yucca Mountain in Nevada led to billions of dollars in expenditure for a project that, as a result of strong local and state opposition, was ultimately abandoned. Nuclear plants themselves, including in our home state of Michigan, have been sites of protests—particularly when decisions about whether to keep a plant running are in play. The nuclear energy sector would likely be better off today had engineers worked hand in hand with communities from the start, gaining local perspective and winning buy-in that might have kept the industry on track.

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Teaching sociotechnical engineering

The courses we've designed are shaped by understanding the importance of the social aspects of engineering work, departing from the traditional focus on purely technical engineering concerns. For example, we've embraced *participatory design*, a valuable tool for engaging communities in the design process that originated in Scandinavia in the 1970s. This conceptual framing has been instrumental in developing disciplines such as human-computer interaction, biomedical engineering, and human factors engineering—and we believe it can be transformative in the field of nuclear engineering as well.

Two of us (Verma and Snyder) created an introductory course, "Socially Engaged Design of Nuclear Energy Technologies," that is a living lab—an open-innovation space where ideas are developed, tested, and iterated in real-life contexts with communities. Students learn the fundamentals of nuclear engineering at the same time as they gain skills in technical communication, qualitative research methods, ethical community engagement, and participatory design. For their term project, they collaborate with community members to design a hypothetical nuclear energy facility in southeast Michigan.

The course is for first-year undergraduates, so we start by teaching them the fundamentals of nuclear energy systems. We give lectures on nuclear physics, fission, and fusion. Across three lab sessions, they explore virtual reality (VR) models of fission and fusion energy systems that were built for the course, using cross-sectional models that they can take apart and label to help them understand the subsystems and their fundamental components. In subsequent labs, they explore facility-level models of fission and fusion systems, which helps convey the scale and scope of these systems and how they might be integrated into a site and community. The labs culminate with students recording tours of the nuclear facilities in a virtual environment. We plan to use those VR models as a participatory design tool in future classes.

The course includes multiple opportunities for students to communicate clearly and transparently with those likely to be affected by their work. Complex sociotechnical systems such as power plants may have a handful of users or operators in the traditional sense, but they affect hundreds, if not thousands, of people's lives and environments in ways that are positive, negative, or both. Students begin by interviewing friends and family from their hometowns, hearing their perspectives on various sources of energy and how their values and preferences influence what they consider desirable and undesirable attributes of those energy sources. Toward the end of the interviews, students ask specifically about the interviewees' views of nuclear energy.

Next, supported by the instructors, the students conduct two virtual workshops with southeast Michigan residents. Again, participants describe their own values and how those values inform their energy choices. Midway through the workshop, participants are introduced to fusion energy and asked whether and how they might wish to be involved in the design and development of a hypothetical fusion energy facility. Some have said they would be eager to help guide design choices for a fusion system coming to their area. That might include weighing in on decisions such as the size of the plant and its impact on land use, job creation, and waste production and disposal. Once a project's parameters are set, community input might then inform the design of the facility that houses the fusion energy system.

Questions we discuss with students and still debate among ourselves include: How will representatives of a community be chosen or appointed? How should disagreements and conflicting priorities or visions among community members—or between the community and the engineers—be adjudicated and resolved? And how might long-established engineers already working in the field be encouraged to collaborate with community members?

We choose to refer to the community collaborators not just as *stakeholders*, but as *rightsholders*. The distinction expresses a central point: communities that host energy facilities—and thereby risk experiencing socioeconomic, environmental, and aesthetic changes—have not only a stake in the project, but the right to participate in the process of design and decisionmaking. Many communities have experienced such impacts in the past but have had little say in either their design or their remediation. Shifting perspective to give communities certain rights in the negotiation process recognizes the need to share power and work collaboratively in energy systems design.

The third and final community engagement is an in-person workshop. Community participants from the virtual sessions bring friends and family and work in teams with students to create designs for hypothetical fusion facilities. Each team's design is unique, shaped by participants' perspectives, values, and experiences. For example, some teams have placed their fusion systems right within the community's boundaries, with shared-use spaces surrounding the facility. Others felt it was important to keep a facility at some distance from residents. Some chose to weave the facility into its natural surroundings, while others prioritized transparency as a key principle, resulting in a design that is literally see-through. Another team wondered how they might repurpose Detroit's industrial infrastructure into a whole new energy industry. Once teams agree on a design concept, they use artificial intelligence image generators to visualize it.

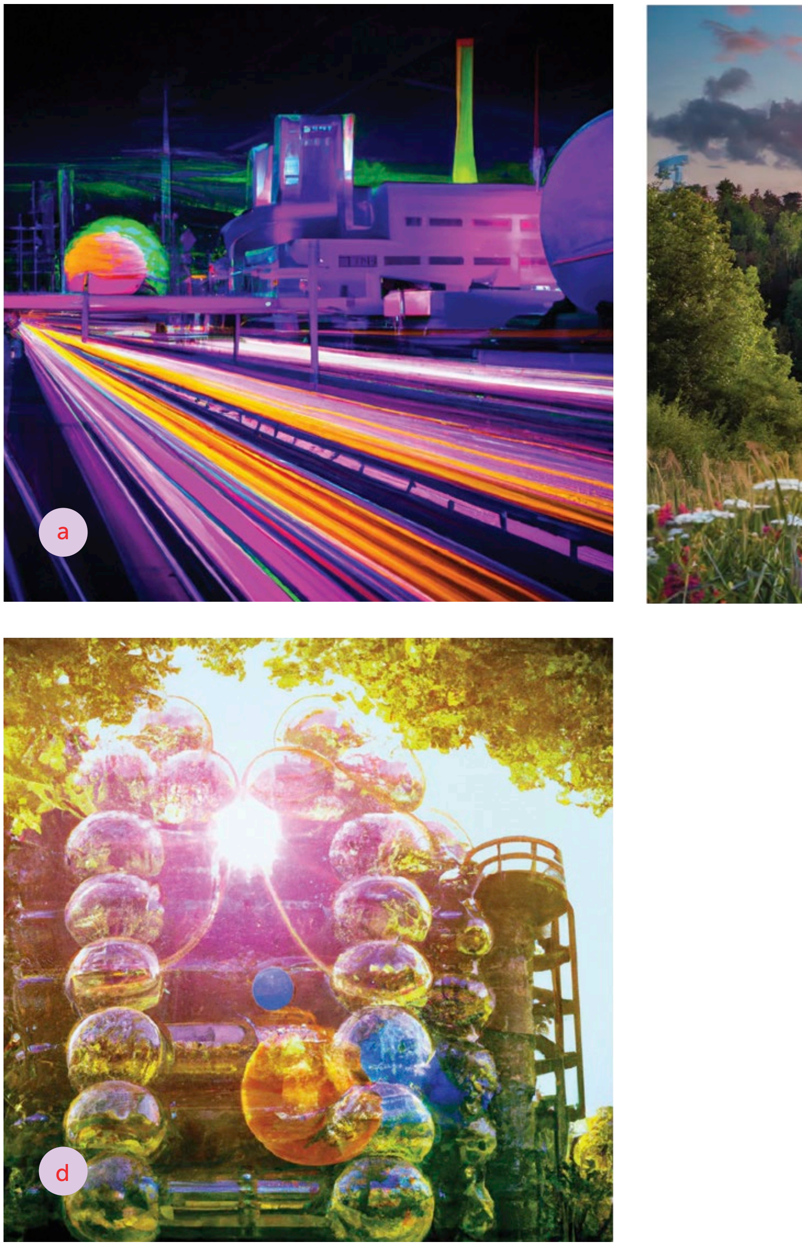
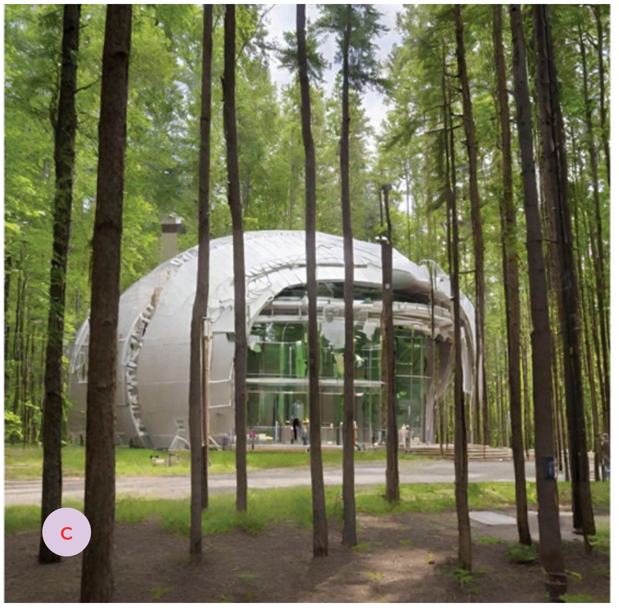
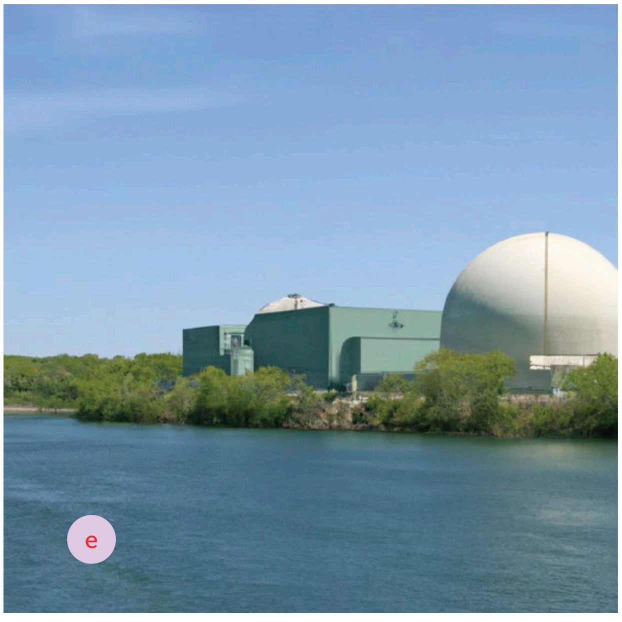
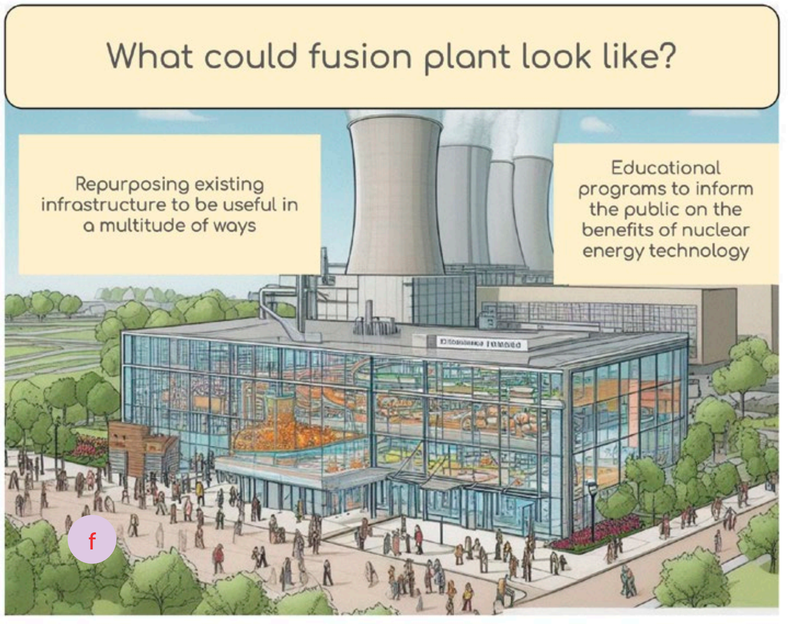


Figure 1. **EXAMPLES OF IMAGES OF FUSION ENERGY FACILITIES GENERATED BY TEAMS MADE UP OF STUDENTS AND COMMUNITY MEMBERS**

The images were generated using Canva AI, Adobe Firefly, and DALL-E2 using the following prompts: (a) A fusion energy facility with colorful lights, sidewalks, and a bullet train rail; (b) A modern designed fusion system with a cooling tower with LED lights on it at sunset with nature and flowers surrounding it. Forest engulfs the background; (c) A futuristic fusion energy facility surrounded by trees; (d) A fusion energy facility with lots of light and bubbles and surrounding greenery; (e) a nuclear fusion facility with giant windows on a river; (f) A transparent fusion energy plant surrounded by plant workers.







Designing energy infrastructure with love as a core value

When it comes to responsible design, nuclear energy requires special consideration beyond the here and now. Engineers must look to the future, both near and distant—up to a million years. What does it mean to design responsibly across such expanses of time? Our students explore this question by designing the surface of a deep geological nuclear waste repository. The exercise forces them to imagine what the world might look like 10 years from now, then 100, 1,000, and 1 million years. They ask who and what might still live around the facility, and how to protect the health and safety of future rightsholders—whether human or not. The workshop helps students appreciate how engineering design decisions can reverberate across generations. More traditional nuclear engineering classes often try to avoid "getting messy" in considering uncertainties, but we've found that an honest approach to designing over deep time is itself a valuable learning experience. Students realize they need to proceed with both humility and imagination to contend with vast uncertainties and awesome responsibilities.

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One surprising outcome of past workshop experiences was our students' greater appreciation of the role of feeling and emotions in the engineering design process. We asked teams to describe their individual and shared values before designing began. *Trust* and *respect* were the dominant themes across all groups, and *love* for the community—both the people and the place—was a core value for several.

Engineers are human, after all, and it would be selling ourselves short to say our work is governed solely by logic and rationality. Engineers find pleasure and joy in bringing something new into the world. We experience boredom, frustration, and a range of emotions that shape design decisions in big and small ways. As teachers, we see this play out, especially during our in-person workshop where students and community members collaborate on the fusion energy facility design. Throughout the day, the teams joke, argue, and negotiate with each other. In their summaries, several students have recounted ways that emotion shaped their design journeys. They felt this collaborative approach should be the norm, and that it connected them to something bigger than themselves, the class, or their education. For their part, community members have said they felt heard, enjoyed working with the students, and were impressed by their knowledge and maturity. Students and community members alike said they were proud of their work together. In the workshop's final presentation, on their last slide, one team summed up their experience in three words: "We loved it!"

We've also been surprised and delighted by how quickly students and participants form a sense of shared purpose and forge a commitment to working together across their differences to find consensus. Many students wrote about the value of the connections they made. One wrote, "The most valuable information about what defines success in design is found within the people directly affected by the design."

In their final presentations, each of the 10 student teams also expressed a desire to engage with rightsholders as part of their future design work. One student said in their team's semester-end presentation: "What we did this semester was a necessary first step for the dream that is a world built on sustainable systems." Another commented, "Our recommendation is to focus on the humanity of engineering and really try to design with the intent that you know you're designing for humans."

Accelerating the new energy economy with care

We know that communities do not hold all the answers when it comes to design or to solving the energy system challenges society faces. Nor do we suggest that taking the community seriously and giving it the respect it deserves is easy. On the contrary, substantive community engagement is time-consuming and sometimes difficult. But the time and effort are well worth the price—particularly in the case of new nuclear facilities, which must be deployed soon enough to slow climate change and in ways that are safe and just. Though it requires an upfront investment of time, collaboration can expedite and smooth project implementation by gaining early community support, avoiding false starts, and helping to navigate potential objections or misunderstandings. And it simply won't be possible to achieve a large-scale renewal of energy infrastructure without an alignment of consent across local communities and actors at the state, national, and even international level.

Engineering must embark on a journey of transformation, challenging the status quo of engineering education and envisioning a future where engineers are deeply considerate of communities. The discipline must make room for engineering solutions that are not just technically sound but also empathic and ethical. In our work, we hope to shape a new kind of engineer—a sociotechnical engineer—who is grounded in the technical knowledge of the discipline while being adept in participatory and human-centered design and ethical, equity-centered communication. We do not believe this approach entails sacrificing technical excellence. Instead, it requires contextualizing it and connecting abstract engineering expertise to real-world problems. What is more, our research, anecdotal evidence, and our own firsthand experiences suggest that this approach to engineering, instead of compromising our world-building disciplines, will draw enthusiastic, talented young people eager to help in ever larger numbers.

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