



What we know about effective public engagement on CRISPR and beyond

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Advances in gene editing technologies for human, plant, and animal applications have led to calls from bench and social scientists, as well as a wide variety of societal stakeholders, for broad public engagement in the decision-making about these new technologies. Unfortunately, there is limited understanding among the groups calling for public engagement on CRISPR and other emerging technologies about 1) the goals of this engagement, 2) the modes of engagement and what we know from systematic social scientific evaluations about their effectiveness, and 3) how to connect the products of these engagement exercises to societal decision or policy making. Addressing all three areas, we systematize common goals, principles, and modalities of public engagement. We evaluate empirically the likely successes of various modalities. Finally, we outline three pathways forward that deserve close attention from the scientific community as we navigate the world of Life 2.0.

public engagement | science communication | deliberation | political communication | public participation

Gene editing technologies are advancing at a fast pace, and it is clear that science and engineering alone will be insufficient to address the social, ethical, and legal dilemmas that are presented not only by current CRISPR applications but by the myriad advancements to come. Expanded applications of gene editing pose “wicked problems” that will require societies to make difficult trade-offs to reach compromises across competing priorities and value systems (1). Such dilemmas are increasingly common in an era of “postnormal” science (2), in which the societal implications of science are so far-reaching and complex that technical expertise invariably falls short in managing them, necessitating governance and regulatory structures that “rely on a multitude of perspectives when assessing risks and benefits” (3).

These dilemmas have led to a growing chorus of voices calling for broad public engagement about CRISPR and its societal applications (4–6). This has been paralleled by increased media coverage in the United States and other countries of public engagement exercises about CRISPR applications in humans (Fig. 1). What is less clear than the interest in and need for engagement, however, are the specific goals behind engagement initiatives. Why is it important (or even necessary) to engage diverse publics in discussions of emerging technologies? What principles can guide our engagement efforts to make them most effective? Which existing modalities of public engagement actually work? And what are the pathways forward for public engagement, especially as they relate to realistic societal and policy outcomes?

The Need for a Comprehensive Framework of “Public Engagement”

“Public engagement” has been used to describe a variety of different activities (7). Given our focus on public engagement with science and the implications of CRISPR in particular, our discussion refers specifically to processes and initiatives focused on enabling public participation in the responsible innovation

and development of new technologies, including the management and assessment of technological risks.

Reflecting broadly on the value of public engagement initiatives, some might argue that such efforts are not necessary in representative democracies like the United States, which already have administrative and legislative structures in place to accommodate citizen feedback. What would be the point of giving people more of a voice? We argue that the challenges posed by postnormal scientific developments such as CRISPR demand new and more effective infrastructures for citizen engagement that go beyond classical modalities of civic participation.

Even as different actors explore a variety of engagement modalities—from consensus conferences to deliberative polls—most of them share a common understanding of certain goals of engagement, whether or not these goals are explicitly stated. In particular, we identify seven goals across work in different communities of scholarship and practice. By connecting these goals to established principles of engagement and to a review of the effectiveness of engagement modalities, we present a framework for understanding public engagement efforts. We close with a discussion of challenges facing public engagement, as well as pathways forward.

Our framework brings together disconnected fields of scholarship and practice. This is not to say that previous work has not differentiated subsets of engagement activities in terms of the “nature and flow of information,” for instance, discussing the likely effectiveness of various formats and broadly asserting their value (7). Similarly, previous work has argued convincingly that not all actors in this space promote public engagement surrounding genome editing for the same reason (8, 9). Our framework goes a step further, however, and accounts for the fact that not all actors have “bought in” to normatively desirable goals such as mutual learning, knowledge integration, or adherence to principles of democracy and justice, in the first place. More specifically, we systematically delineate implicit strategic goals, such as placating potentially resistant consumers or persuading lay publics to align their goals with those of the scientific community, from explicitly engagement-focused goals, such as learning or the deliberative exchange of ideas, and more abstract normative goals tied to the broader democratic ideals underlying many engagement efforts.

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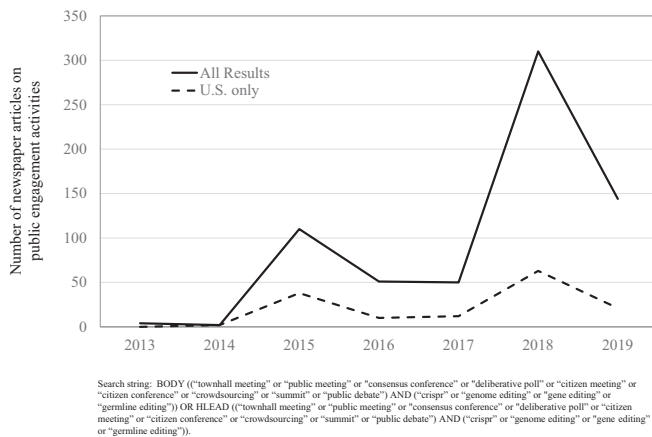


Fig. 1. Lexis Nexis appearances of CRISPR and human genome editing-related public engagement activities in the United States and globally from 2013 to 2019.

This more exhaustive examination of goals is crucial. Some of the unstated strategic goals in some communities (e.g., among bench scientists) are likely to create types of engagement that are at odds with more normative goals that predominantly guide public engagement in other fields (e.g., scholars in science and technology studies), because they emerge from different scientific communities and from practice, as we mentioned above. The different goals also necessarily alter our evaluations of engagement—that is, the effectiveness of a given modality should be assessed differently, depending on its goals.

Seven Goals of Public Engagement with Science

Our discussion of potential goals lays the foundation for the framework outlined in Fig. 2. The framework delineates a total of seven goals, ordered loosely based on the extent to which diverse publics might meaningfully exert influence on policy or the scientific enterprise itself. We discuss this point in more detail at the close of the paper.

This framework is not designed to represent all possible goals, principles, or modalities of public engagement with science. Rather, we utilize this framework as an analytical tool to shape our review of empirical evidence as to the effectiveness of public engagement efforts.

Similarly, many engagement efforts are (and should be) reflective of multiple elements of our framework simultaneously. There is no “one-size-fits-all” approach to successful engagement, and we comment on this in more detail in *Challenges: Why Real Engagement on CRISPR Has Remained So Elusive*. In part, this is because “the public” is not a monolithic entity; instead, there are many different “publics” whose values, beliefs, socioeconomic circumstances, and risk perceptions are varied. In the case of CRISPR, there is no single engagement modality that will equally suit all publics (e.g., farmers, physicians, pharmaceutical companies, policy makers, and so on). Instead, repertoires of approaches will realistically be required, with careful attention to the unique needs of different publics and to the demands of the specific issue context.

Avoid Potential Controversy. One often implicit and strategic goal of public engagement is to avoid public controversy and, in so doing, to promote adoption of a technology (10), or at least to steer public opinion in a direction desired by the scientists involved with the research. In some cases, this rationale for engagement is well intentioned and may even be informed by empirically grounded beliefs about the role of individuals’

subjective perceptions—such as their trust in experts—in science and risk communication contexts.

Indeed, scientists’ perceived warmth is an important component of trust in them (11), and likeable or friendly scientists tend to be seen as more convincing (12). For these reasons, one important function of engagement initiatives is to send the trust-building signal that scientists want to “listen” to nonscientists. However, when fostering trust becomes either the primary or sole goal of a so-called “engagement” effort, the initiative risks becoming a hollow performance.

Importantly, institutions and other actors who fall into this trap are presumably not trying to manipulate or deceive but are, instead, either limited in resources or exhibiting a knee-jerk reaction to previous public communication. A concrete example is what we would call “the ghost of GMOs past,” or the rising concerns that certain CRISPR applications might trigger public opposition of the kind that genetically modified organisms (GMOs) triggered when they first entered the marketplace: “Without increased consumer acceptance—likely achieved by improved methods of education and public engagement—CRISPR agricultural applications may face the same regulations and challenges of traditional GMOs, hampering CRISPR’s contribution toward feeding a growing global population” (13).

Avoiding the specter of past mistakes is a worthwhile goal. But strategically using the pretense of an “honest, bidirectional dialogue,” as former American Association for the Advancement of Science CEO Alan Leshner (14) called it, simply to foster trust or consumer acceptance has serious pitfalls. Not only is this approach disingenuous from the spirit of equitable deliberation, but it is also problematic with respect to societies being able to meaningfully assess all potential benefits and risks of emerging technologies.

Educate the Public. A related perspective, especially among scientific and sometimes policy-making communities, is that a primary purpose of public engagement should be to educate the public and “correct” what some experts consider unreasonable objections to emerging genome editing technologies. Surveys of members of scientific associations, for instance, suggest that this kind of “knowledge deficit thinking” is alive and well in the scientific community, with many members “prioritiz[ing] communication designed to defend science from misinformation and educate the public about science” (15).

Concerns about an underinformed or misinformed public are understandable. Democratic decision-making depends, at least partly, on the idea that citizens and policy makers have access to the best available scientific information when making choices. However, decades of research on heuristic decision-making (16) has shown that correcting individuals’ “knowledge deficits” likely won’t be enough. All of us make those choices while relying, to some extent, on existing values and other predispositions. A reliance on values and other mental shortcuts can also lead to motivated reasoning and a resulting reinforcement of our initial views (17). In fact, motivated reasoning is often strongest for citizens who have the most strongly held beliefs and/or are the most involved in or knowledgeable about scientific issues (18, 19). As a result, well-intentioned efforts to engage publics in order to “educate” them can backfire and result in more polarized views that are split along value lines (20).

Build Democratic Capacity through Deliberation. Moving toward more explicitly engagement-focused goals, the active involvement of various publics with policy-relevant issues—typically in the form of public “deliberation”—is also a core part of normative democratic thinking. Building on centuries of philosophy from Immanuel Kant to Jürgen Habermas, some modern work defines “deliberation” as social interaction that is “marked by reason-giving and inclusion,” in which participants not only

| GOALS | | | | | | |
|-----------------------------|--------------------|--|--------------------------------|--------------------------------|-------------------------------|--------------|
| Avoid potential controversy | Educate the public | Build democratic capacity through deliberation | Widen representation of voices | Solicit input on value debates | Enable responsible innovation | Shape policy |
| PRINCIPLES | | | | | | |
| Quality of outcomes | | Legitimacy of outcomes | | Administrative efficiency | | |
| MODALITIES | | | | | | |
| Communication | Consultation | Involvement | Collaboration | Empowerment | | |

Fig. 2. Goals, principles, and modalities of effective public engagement.

engage in rational reflection on an issue's multifaceted considerations but do so with a willingness to consider viewpoints that may be opposed to their own (21). When successful deliberation occurs, the presumed result is a more knowledgeable and tolerant citizenry that can provide useful input to its representatives, who are then empowered to make decisions that ostensibly reflect the true collective will.

Some have argued that this democratic ideal has been difficult to achieve, in part, because the evolution of American institutions has emphasized equality of representation over infrastructure for deliberation (22). From this perspective, engagement initiatives have historically focused too heavily on the provision of feedback to elites, rather than on cultivating space for an informed public to engage in the “weighing” of ideas and viewpoints. Public engagement focusing on deliberation thus, at least theoretically, aims to increase “sophistication” in participants' attitudes and beliefs (23), or to increase citizens' willingness to reflect with an open mind on others' views, enabling them to interact with sincerity and civility across lines of difference (24).

Of course, public engagement that implicitly or explicitly aims for a Habermasian version of public deliberation can result in engagement modalities that hinge on small-group, well-moderated discussions, akin to the style of conversation found in the “salons” and coffeehouses of a bygone century. Although such interactions may sometimes occur, these contexts and styles of interaction are often difficult to produce and to facilitate, and they are unlikely to scale well. Their ecological validity is also limited by the fact that audiences now obtain much of their information about issues like gene editing through online channels and social media (25–27).

Widen Representation of Voices. Truly “democratic” public engagement, as envisioned in goal 3, is based on the implicit assumption that all relevant voices in society are being heard in public debate. Toward that end, a fourth goal of public engagement efforts is to create forums for previously excluded voices and perspectives that would not have emerged if scientific experts or other “elite” actors had simply deliberated among themselves.

CRISPR and other gene technologies have raised questions that go well beyond the discussions of technical risks and benefits identified by bench scientists. However, genome editing tools have also raised questions that surpass the ethical and sociopolitical concerns raised by social scientists and ethicists (4, 28), underscoring the fact that a comprehensive assessment of the promises and perils of human gene editing can only emerge through highly inclusive public engagement.

“[D]eliberative processes,” as some observers have noted, “need to be recursive as well as inclusive. The initial framing of an issue shapes the analysis of alternatives, whether scientific, ethical, or political... [H]ighly scripted deliberations that ‘engage’ a limited range of citizens in terms that are defined in

advance... fail to reach the poor, the marginal, and the socially excluded in meaningful ways. They afford little opportunity for the emergence of dissenting voices and perspectives that challenge experts' imaginations” (4).

Solicit Input on Value Debates Triggered by Science. A fifth goal of public engagement focuses on the need for science to address value-based concerns as they arise in public discourse. As we discussed earlier, new genome editing tools like CRISPR have raised and will continue to raise ethical, regulatory, and sociopolitical questions that go well beyond the discussions of technical risks and benefits identified by bench scientists (4) and even beyond the ethical and sociopolitical concerns raised by social scientists and ethicists (28). This fifth goal, in other words, is focused on engagement not as a tool for assessing or weighing technical risks but instead to raise and bring to the forefront ethical and moral questions that emerge from CRISPR science and its applications.

The need for these debates is exacerbated by the speed with which CRISPR and its potential applications have emerged worldwide. It has created a bottleneck problem for societies trying to address the host of ethical, societal, and regulatory questions that arise almost simultaneously in the wake of this new technology. Or, as ethicist George Khushf puts it, “The more radical the technology, the more radical the ethical challenges... We are already approaching a stage at which ethical issues are emerging, one upon another, at a rate that outstrips our capacity to think through and appropriately respond... On the immediate horizon arises a point at which the traditional way we have addressed ethical issues fails, because it does not and cannot keep up with the rate at which new challenges emerge. Faced with the prospect of increasingly accelerating, radically new technologies, we must completely reassess how ethical issues are addressed and how ethical debate informs broader public and legal policy” (29).

As the scientific community and governing bodies—such as the Food and Drug Administration or the US Department of Agriculture—attempt to evaluate the implications of technologies like CRISPR, the interplay of scientific and value-based complexities virtually guarantees that, without effective public engagement, the considerations under discussion will fail to represent the full range of stakeholder concerns.

Enable Responsible Innovation. A sixth goal of public engagement with science is the notion that individuals and groups working to advance the scientific enterprise have a duty or obligation to the broader social collective that is continually investing in science for the larger social good (30). Discussions of public engagement that are motivated by this goal tend to recognize that involving publics “too late” in the development cycle of new technologies signals a disregard for the significant investment societies make in public and private research infrastructures. Perhaps more importantly, underutilizing public engagement as a mechanism to inform the research enterprise also fails to maximize possible societal returns from investments in science. Without early public input, there is a heightened risk of investing too heavily in science and technology that different publics neither want nor need (31).

Public engagement efforts operating within this goal therefore often argue for models like “real-time technology assessment” (32) or “deep interdisciplinary R&D” (33), both of which are strategies to involve social scientists and lay publics as early and as often as possible in the development lifecycle, such as farmers in the editing of crop genetics. The hope behind these approaches is to allow nonscientists and (social) scientists to collaboratively and proactively shape the direction of scientific advancements rather than retroactively evaluating fully developed technologies that, if derailed, would represent a heavy

economic loss or even a competitive disadvantage for those who have invested in it.

Shape Policy. A final goal focuses on the policy impacts that public engagement can or should have. In subsequent sections, we discuss a wide variety of modalities of engagement that come with an equally wide variety of expectations about how binding their influence is on the policy-making process. Many of these differences are tied to specific national regulatory structures that differ significantly across countries.

Perhaps the most widely cited exemplars of public engagement explicitly designed to inform policy making are the Danish Consensus Conferences. They are organized by what was originally called the Danish Technology Board (DBoT), an independent body established by the Danish Parliament. Based on consensus conferences and other public engagement mechanisms, the DBoT advised the Danish parliament and government (34). Danish consensus conferences are often cited as models for efforts in the United States to involve the public in the governance of science (e.g., refs. 35 and 36) and have inspired congressional mandates for public engagement efforts attached to funding for major scientific initiatives in the United States, such as the 21st Century Nanotechnology Research and Development Act.

Interestingly, however, even reasonably well-funded government initiatives like the Danish Consensus Conferences have had limited success in actually informing or influencing policy, as illustrated by surveys of Danish lawmakers. Although three in four lawmakers (75%) were aware of consensus conferences, only one in five of those who were aware (21%) indicated that they “usually” read resulting reports, and only about one in three members of parliament who were aware of the conferences (29%) reported that the reports “sometimes lead to parliamentary initiatives,” such as legislation or guidelines (37). In other words, even some of the most formalized efforts to meaningfully tie engagement to public policy in countries like Denmark have had limited success. We return to this challenge at the end of this essay.

Where the Rubber Meets the Road: Key Principles and Existing Modalities of Public Engagement

While efforts to engage the public on genome editing technologies might be motivated by different (combinations of) goals, three established principles have emerged across different social scientific literatures for how public engagement must be approached to be most effective: 1) Improve the quality of outcomes such as policy decisions, 2) improve the legitimacy of those outcomes, and 3) balance the need for administrative efficiency (6, 9) (Fig. 2).

To improve the quality of outcomes for all stakeholders, engagement initiatives must go beyond the simple provision and discussion of “the facts” among lay publics. They must also involve the consideration of individuals’ values, interests, and risk and benefit perceptions. Toward that end, the quality of outcomes depends on an atmosphere of inclusivity by demonstrating respect for everyone involved and by communicating openly in good faith.

Building on this notion of communicating openly, the principle of improving legitimacy of outcomes involves ensuring that the decision-making process is transparent, so that all affected parties can judge whether it is fair and competent, and whether it is in line with current laws and regulations. Being “transparent” also includes being explicit about assumptions and uncertainties.

As ideal as it is to abide by the first two principles—that is, to focus on the quality and legitimacy of engagement outcomes—these aims will be undermined if they are not balanced against the need for administrative efficiency. Policy makers have finite time and resources to devote to any given decision, and public engagement processes need to fit in these realities of

policy-making environments. However, with an eye toward legitimacy and quality of outcomes, there also needs to be time for iterations in collectively identifying problems and potential solutions.

While these principles are, indeed, important guideposts to ensure that engagement efforts will be as effective as possible, there remains, in our view, a glaring omission: This set of principles stops short of providing guidance about what should come after an engagement is complete. We will address this issue more thoroughly in our concluding section below on *Engagement “with Teeth?”*, where we argue that we need engagement that loops back into policy. Before grappling with this idea, however, we will first review engagement modalities that have been deployed in various settings and some empirical evidence of the pitfalls they face.

In terms of adherence to the above principles and the likelihood of satisfying a given “goal” for public engagement, some modalities are more suitable than others. While it is beyond the scope of this paper to discuss all existing modalities in detail, at least five clusters of existing engagement activities emerge across different literatures and fields of practice. We present them ordered by the extent to which the public has an influence on what the initiators of the engagement activities do or decide: 1) communication, 2) consultation, 3) involvement, 4) collaboration, and 5) empowerment (Fig. 2).

Public communication simply focuses on providing publics with decision-relevant information. It involves the top-down, one-way flow of information from those initiating an engagement (regulatory or governmental agencies, for instance) to various publics. Examples of this modality are newsletters, public service announcements, or informational outreach through legacy and social media.

Public consultation occurs when initiators of public engagement seek feedback on potential policy decisions from those who are or will be affected by those decisions. Even though public consultation involves soliciting public feedback, it remains one-way communication. The initiators of this type of engagement activity retain decision-making authority. Referenda, group-based citizens’ panels, surveys, or focus groups all fall under the umbrella of public consultation. Concrete examples include the European Commission’s program Views, Opinions and Ideas of Citizens in Europe on Science, or public consultations initiated by the French National Consultative Committee on Ethics. Public consultation might also happen online and asynchronously. In 2014, the Ministry of Justice in Finland used crowdsourcing, for example, to identify issues about housing companies and to find solutions for those issues (38). Current participation levels in scientific crowdsourcing online, however, are quite low: Only 3% of respondents in a US survey said they ever contributed to a science-related online crowdsourcing activity (39).

Public involvement is interactive and involves the exchange of fact-based information as well as information about values, beliefs, and perceptions between participants in the engagement (i.e., members of the public and, typically, experts or policy makers). Deliberative opinion polls are often used as vehicles for public involvement, wherein participants are polled before and after deliberation on the issue with experts (7).

Public collaboration involves not only dialogue among participants but also active collaboration to identify and design workable solutions to the challenges under discussion. Consensus conferences are an example of this modality. First conducted in the 1980s in Denmark, but widely adapted by other countries as well (35, 40–42), consensus conferences provide space for representatives of the public, experts, and policy makers to exchange values and existing knowledge, and to create new ideas together. A key characteristic of consensus conferences is that, after a subset of the invited participants actually agree to be

involved, the initiators of the consensus conference select another subset that is representative of the public (43). Then, members of the representative selection are provided with information on the issue so they can prepare for discussion at the conference, where they are expected to come to a consensus about the issue. The results of consensus conferences, at least in the Danish case, are used to advise the parliament and government in their policy decisions.

Like consensus conferences, a program in the United Kingdom called Sciencewise brings public representatives, experts, and policy makers together to discuss their views and knowledge on new scientific or technological developments, with the goal of looping results back into the policy-making process (44). In contrast to the Danish model, Sciencewise's aim is not necessarily to find consensus: "The context and objectives for the process will determine whether it is desirable to seek consensus, to identify where there is or is not consensus, and/or to map out the range of views" (45).

Public empowerment, finally, is the form of public engagement that confers the most power onto participating publics. It is designed to provide members of the public with enough information to formulate and come to an informed formal decision (by, for example, formally voting on policy options). This decision is then binding on the affected publics. As we discuss later, public empowerment tends to be rare because, in most countries, policy makers and regulatory actors are not allowed to transfer their decision-making authority to the public.

Evaluating Engagement: Even the Most Promising Approaches Have Pitfalls

The proliferation of public engagement efforts does not mean that all efforts produce desirable outcomes. In fact, due to various intrinsic and extrinsic constraints, many existing engagement modalities do not live up to the principles and goals of effective engagement.

Intrinsic Pitfalls. Some pitfalls of public engagement are intrinsic to the very format of deliberative meetings. We especially highlight two intrinsic problems here: 1) low and highly selective participation by members of the public and 2) the "violation of key deliberative principles during the [engagement activity]" (43).

While many people like the idea of public engagement and meetings, only very few ever (or in the last year) attended one: Four in five (81%) Americans think it is very important for members of Congress to personally attend town halls or meetings to hear from the people they represent, and another 14% see this as somewhat important (46). For human genome editing specifically, surveys show that Americans tend to agree that "[s]cientists should consult with the public before applying gene editing to humans" (on a seven-point scale with 1 = "Strongly disagree" and 7 = "Strongly agree": $M = 5.2$; $SD = 1.51$) (5). However, nationally representative surveys also show that only one in eight (13%) Americans attended either public hearings or town/city council meetings on any issue in the past year (47).

Exacerbating this problem of nonattendance, many public engagement initiatives still rely on face-to-face formats, which can hinder participation for three reasons: 1) Societies like the United States are simply too large for representative face-to-face participation to be practical or scalable, 2) the level of heterogeneity in citizens' views on any given issue makes face-to-face discussions difficult to manage, and 3) face-to-face meetings will be increasingly difficult to organize in a post-COVID-19 world.

Key deliberative principles can also be violated when some groups systematically dominate discussions during engagement exercises. The assumption for all deliberative exercises, of course, is that rational, fair, and goal-directed exchanges among citizens are responsible for achieving quality outcomes. As a result, well-conducted public engagement exercises are moderated and

monitored to minimize imbalances in the conversation based on gender, socioeconomic status, and other participant characteristics (48). Unfortunately, group dynamics and personality characteristics of participants have been shown to play an important role in producing the outcomes of discussions. In particular, during some engagement exercises that used small-group discussions with about 13 to 15 people per group, the five most outspoken members in each group made more than half of all of the comments recorded during the discussions. The five least outspoken participants accounted for less than 8% of the comments (49).

Extrinsic Constraints. In addition to intrinsic concerns, there are also concerns about the potential real-world applicability of public engagement exercises. Well-conducted public meetings or consensus conferences try to minimize potential conversational imbalances due to demographic, cognitive, or personality characteristics of participants by carefully moderating conversations and controlling the a priori information environments that participants are exposed to. This creates a catch-22, since these artificial illustrations of "the conclusions people would come to, were they better informed on the issues and had the opportunity and motivation to examine those issues seriously," (50) tell us little about what happens in real-world settings. By carefully moderating and guiding conversations, consensus conferences create captive audiences (51) who behave in ways that may be substantively different from what is likely to occur in real-world discussions.

This is particularly problematic since some federal agencies and communities use public meetings as a gauge of public support for policy choices. A study examining the social dynamics surrounding the site selection process for the National Bio- and Agro-Defense Facility (for an overview, see ref. 52), for example, showed that the selective discourse surrounding public engagement exercises may, in fact, lead policy makers to embrace conclusions that are diametrically opposed to public preferences measured more systematically in surveys (53). In other words, the very idea of creating engagement exercises that are immune to some of the dynamics normally governing social life might also limit the generalizability of their findings to real-world policy scenarios.

Challenges: Why Real Engagement on CRISPR Has Remained So Elusive

Regardless of any potential pitfalls, the mandate for public engagement is difficult to ignore. CRISPR is a prime example of postnormal science. Decision stakes are high, and margins of error are thin, especially once we cross the bright red line of editing the human germline and begin making edits heritable. At the same time, CRISPR raises a host of ethical, social, and regulatory conundrums that all introduce systems uncertainty that make it difficult to map the best paths forward.

This makes effective public engagement more important than ever before. Outside of the United States, increasing pressure to engage different publics on CRISPR has led to sporadic efforts, often funded or led by philanthropic organizations such as the United Kingdom's Wellcome Trust. However, sporadic efforts likely will not be enough, and the question remains as to why increasing calls for action have not led to broader investment in sustainable infrastructures for public engagement, especially with an eye toward informing policy and rulemaking on technologies like CRISPR. We argue that at least three influences have slowed progress on this front and require attention from the scientific and policy-making community.

No One-Size-Fits-All Models: The Need for Systems Thinking. Even if incentive systems and infrastructures were in place, a second challenge for scalable public engagement exercises remains: the absence of a single modality of engagement (Fig. 2) that can be

deployed across intended outcomes and contexts. As a result, there are no blueprints with universal or even broad applicability. This does not mean, of course, that there are no commonalities. Public engagement efforts often share overlapping goals and, in many cases, try to adhere to the principles outlined in Fig. 2. But the concrete modalities employed by sponsors of public engagement exercises vary across at least five different dimensions: 1) intended outcomes, 2) (the stage of) the issue/controversy, 3) social and policy contexts, 4) intended participants/stakeholders, and 5) resources available.

Engagement exercises designed to create a consensus report on policy options, for instance, will require input from (and representation of) very different stakeholders than public engagement exercises with patient groups that are designed to cocreate agendas for developing CRISPR-based therapies. Similarly, engaging small groups of highly interested publics can help flag concerns or unintended outcomes early in the issue cycle. Those types of upstream initiatives, however, require a very different level of resources and attention to political context compared to public engagement later in the issue cycle, when visible public conflicts about values and other political considerations have already shaped the opinion landscape.

Designing effective public engagement, therefore, involves careful calibration along the five dimensions outlined above (and potentially more). Realistically, scientists and other sponsors of public engagement exercises have control over only some of the dimensions, such as timing, intended outcomes, or available resources. This makes it even more important to design public engagement exercises that are responsive—in both content and modality—to the realities of the policy environments, consumer concerns, or societal debates they are trying to inform. We thus need to apply integrated systems thinking (54) to improve our “science of public engagement.” Effective public engagement on CRISPR and other emerging genome editing technologies, in other words, will require sustained interdisciplinary collaborations across the social sciences and natural sciences to develop and evaluate modalities for public engagement that are responsive to stakeholder needs and designed to maximize intended outcomes.

The Need to Build Infrastructures and Incentive Structures for Scientists. A second challenge involves incentive systems and infrastructures related to public engagement for scientists within academia, government, and the private sector. While industry scientists likely have a different balance between research and other responsibilities as compared to their academic colleagues, for example, there are no obvious incentives for either group to add public engagement to their existing workload. In fact, the absence of easy-to-follow blueprints for public engagement and the level of controversy that can surround engagement efforts (52) likely serve as disincentives for scientists worried about their personal careers. It is therefore both surprising and encouraging to see signs of a sea change.

In a recent large-scale census survey of science faculty at 73 colleges and universities within the US land-grant system, “a majority . . . indicated that pursuing public engagement activities is highly important to them, with younger science faculty . . . placing significantly higher importance on such activities” (55). The same survey, however, also showed very mixed perceptions of how valued public engagement and related activities were among colleagues and administrators at their university. Building both infrastructures for sustained public engagement and incentive structures for scientists to become active participants in these infrastructures is therefore in the self-interest of scientific institutions. Aside from achieving the goals for public engagement we discuss in Fig. 2, there may also be some collateral benefits from public engagement. As a report on a 2015 meeting at the University of Michigan on academic engagement in public

and political discourse put it, “If academia does not embrace the opportunity represented by public engagement it runs the risk of losing the best and brightest young scholars who ‘want to make a difference’ through their work, further reducing diversity in its ranks” (56). Engagement, in other words, has to become part of the DNA of academic institutions.

Even if an openness to engage with public stakeholders were to become more prevalent among the scientific community, there are few existing mechanisms that scientists can easily leverage to get such efforts off the ground. This problem is further exacerbated by the fact that COVID-19 has made it impossible for scientists to utilize the face-to-face mechanisms that are in place in the foreseeable future. Building infrastructure—both offline and online—is therefore imperative. And models for doing this do exist. Anticipating a need for both academic and societal infrastructures to foster broader societal debates about emerging technologies, the US NSF funded two large collaborative Centers for Nanotechnology in Society in 2005 to study the ethical, legal, economic, and policy implications of the relatively new, nature-altering science called nanotechnology.

Calling for a similar harnessing of the work of social scientists, ethicists, bench scientists, and other societal stakeholders to help guide societal responses to CRISPR, some scholars have proposed the idea of “a global observatory for gene editing, as a crucial step to determining how the potential of science can be better steered by the values and priorities of society. This would be an international network of scholars . . . dedicated to gathering information from dispersed sources, bringing to the fore perspectives that are often overlooked, and promoting exchange across disciplinary and cultural divides” (57). Regardless of the specific form that such interdisciplinary infrastructure-building efforts might take, they will be crucial for providing equitable, inclusive, and legitimate platforms for the broad conversations about CRISPR that we know are on the horizon.

Engagement “with Teeth?” A final challenge relates to the degree to which engagement efforts can and should provide meaningful input into formal policy making. Philosophically, many (if not all) of the goals of public engagement we outline in Fig. 2 are based on at least an implicit assumption that there will be some feedback loop from each modality of public engagement to the decisions made by legislative bodies, or other rulemaking at the policy level. The tricky part with this assumption is that there is little evidence to support it. This is not too surprising for at least two reasons.

First, many federal agencies—at least in the United States—are limited by law in the degree to which they can provide the public with formal opportunities to make decisions: “In general, agencies are not permitted to delegate their decision authority to the public, and creating a fair, legitimate, and inclusive process for empowerment beyond basic voting is complex and challenging” (58). Within these legal frameworks, advisory bodies like NIH’s Recombinant DNA Advisory Committee (RAC) for human genome editing trials have historically allowed for what could be called “passive” forms of engagement that provided opportunities to interested publics and stakeholders to overhear and provide public comment on parts of RAC meetings. Unfortunately, as the National Academies of Sciences, Engineering, and Medicine’s consensus report on human genome editing put it, the RAC, “[i]n its current form . . . lacks scholarly expertise in public opinion or public engagement research, and is therefore not as well positioned to spearhead efforts to seek input from, or dialogues with, different communities of people at large who have an interest in the issue at hand” (9). Even with the Novel and Exceptional Technology and Research Advisory Committee that replaced the RAC as the “committee for advice and transparent discussions about the scientific, safety, ethical, and social

issues associated with emerging biotechnologies” (59), that expertise, and therefore capacity constraints, remains in place.

Second, partly as a result of the constraints faced by federal agencies in integrating meaningful public engagement into their decision-making, some see federal bioethics commissions as a conduit between public views and the policy realm. Interestingly, both bench scientists and ethicists have questioned the ability of bioethics commissions to adequately represent public views. Biochemists Jennifer Doudna and Samuel H. Sternberg (60) call for a societal debate that goes beyond “researchers and bioethicists, but also [involves] a great range of stakeholders, including social scientists, policy-makers, faith leaders, regulators, and members of the public . . . [and] the conversation should begin immediately, before further applications of the technology thwart [t] any attempts to reign it in.” Concerns about bioethics commissions being effective conduits for input from a broad range of publics are also raised by ethicists, who worry “that the structure of decision-making in those commissions means that the public is unlikely to have its values properly portrayed and, more problematically, the public cannot be portrayed as saying ‘no’” (61).

This is not to say that public engagement will or should replace policy making. But, in an ideal world, public policy on CRISPR

should be responsive to the types of broad and inclusive engagement discussed in this essay. As John Holdren et al. (31) put it during the previous administration, “Public participation is important for promoting accountability, for improving decisions, for increasing trust, and for ensuring that officials have access to widely dispersed information.” As more and more CRISPR applications emerge in human, plant, and animal biology, one could envision a future in which regulation or even legislation explicitly responds to insights from public engagement efforts, even if it is just to outline reasons why they were not taken into account. Either way, future science policy should be informed at least as much by broad public engagement on CRISPR as it is informed by the science itself.

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