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Working Paper

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Executive Summary

Synthetic biology (SynBio) is a dynamic multidisciplinary field with strands of research and development occurring in different socio-cultural contexts within the United States and across the globe. Scientists, developers, and policymakers generally support the notion of public and stakeholder engagement (PSE) to create spaces for public audiences to learn, discuss, and contribute their voices and perspectives to the development of emerging biotechnologies. However, pathways to realizing effective PSE within the development arc of SynBio tools and technologies are few and far between. This paper provides a background for researchers and developers to understand the importance of PSE and provides overviews and examples of different methods for effective PSE activities. While this is not an exhaustive how-to document, this paper can be used to think through why and how one might integrate PSE activities into new or ongoing research projects.

Keywords: Stakeholders, Engagement, Public, Outreach, Lectures, Education.

Abbreviations: public and stakeholder engagement (PSE), research and development (R&D), responsible research and innovation (RRI), science and technology (S&T), synthetic biology (SynBio).

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Why Pursue Public and Stakeholder Engagement?

In a democratic society, scientific work is usually left to those with the specialized expertise to design experiments, develop research programs, test new theories, and properly deploy emerging science and technology (S&T). In the public sector, scientific research and development (R&D) is directed to benefit the broadly conceived "public" because it is funded by state and federal tax dollars. Publicly-funded research is expected to contribute to the well-being of the citizenry by producing beneficial knowledge, evidence-informed policies, development of new methods of practice (e.g., medicine, conservation, civil engineering, etc.) or the deployment of new technologies (Allen 2013; Sampat 2011; Zuniga and Wunsch-Vincent 2012). By this mechanism, publics are directly implicated in the practices of funding scientific research, and they are affected by the impacts of new knowledge and technological innovations. However, it is not always clear how public values, interests, or needs become reflected in scientific research.

Scientists, developers, and policymakers do not conventionally bring public audiences into practices of research and development as those tasks are left to people with specialized expertise and decision-making authority. Public and stakeholder engagement (PSE) can bridge those who conduct basic R&D with the communities affected by its outcomes (AAAS 2025). For the purposes of this paper, one can refer to the working definition of S&T Public and Stakeholder Engagement (PSE) as a broad spectrum of activities that brings different groups in society into discussions, dialogues, and interactions around questions and issues pertaining to scientific research and development (AAAS 2025; Blackburn et al. 2023; Rowe and Frewer 2004). PSE activities can help to build public awareness and understanding of new S&T, provide opportunities for public audiences to inform and influence R&D, and reinforce trust between experts, key stakeholder groups, local communities, and broader publics (Iltis, Hoover, and Matthews 2021; Selin et al. 2017; Stilgoe, Lock, and Wilsdon 2014).

The downside of not utilizing PSE is that the scientific research process is largely insulated from exposure to public values, concerns, and preferences. Conventional upstream development of new S&T has been critiqued for mainly reflecting the values, preferences, and interests of powerful, influential social groups, and responding more often to demands of commercial markets more than critical public-sector issues of public health, environmental safety, and education (Stilgoe, Lock, and Wilsdon 2014; Weingart, Joubert, and Connoway 2021; Guston 2014a). Over time the scientific research enterprise may stray away from serving critical public sector issues that are in the best interests of broader publics and become unfamiliar and untrustworthy to public audiences (Marris and Rose 2010; Stirling 2008). PSE theories, concepts, and methods offer a solution space to help bring public audiences closer to the development of emerging S&T in different ways and at different levels. The goal of PSE is to link communities of researchers, developers, and publics closer together through feedback loops that help guide and produce equitable societal outcomes with S&T at local, regional, and even national scales (Weingart, Joubert, and Connoway 2021).

Key Term — Definition of Public and Stakeholder Engagement

S&T-ASSOCIATED **PUBLIC AND STAKEHOLDER ENGAGEMENT (PSE)** IS A BROAD SPECTRUM OF ACTIVITIES THAT SERVES TO BRING DIFFERENT GROUPS IN SOCIETY INTO DISCUSSIONS, DIALOGUES, AND INTERACTIONS AROUND QUESTIONS AND ISSUES PERTAINING TO SCIENTIFIC R&D.

Sources: AAS 2025; Blackburn et al. 2023; and Rowe and Frewer 2004.

PSE is especially important as a democratizing tool for emerging biotechnologies. The history of public debates and controversy around past biotechnologies such as genetically-modified crops (Kleinman, Kinchy, and Handelsman 2005; Nelkin and Marden 2004; Abbas 2018), human embryonic stem cell research (Robertson 2010), gene therapy (Ansah 2022), and human heritable germline editing (Rainie et al. 2022; Sufian and Garland-Thomson 2021) has shown that biotechnology can be a contentious space. PSE can help navigate issues centered on the manipulation and engineering of life, the intrinsic value of different forms of life, and how new biotechnologies may disrupt cultural norms, practices, and relationships between different life forms. In addition, who has the power over life is an extremely important political issue across health care, agriculture, and environmental decision-making. A more democratic approach to settling political disputes over SynBio requires considering multiple vantage points that could play a role in shaping the course of biotechnological innovation (Iltis, Hoover, and Matthews 2021; Dixon et al. 2022; Anderson et al. 2012). Furthermore, biotechnology manipulates knowledge of life and living things. Therefore, whose knowledge is actualized through biotechnology is significant. This shapes the trajectories of research questions, problem identification, and creation of technologies. Diversified knowledge and perspectives from different cultural backgrounds can productively inform the design and decision making for more robust and inclusive technological development (Hartley et al. 2023; Barnhill-Dilling, Rivers, and Delborne 2020; Popp 2018; Thorton and Scheer 2012).

Benefits for Researchers

PSE offers a range of meaningful benefits for researchers beyond traditional academic outputs. At its core, PSE involves connecting research with wider society — communicating findings, gathering input, and collaborating with communities, stakeholders, and non-academic audiences. This exchange not only makes research more accessible and relevant but also enhances the quality, reach, and impact of the work itself (Garrison et al. 2021; Carter, Mankad, and Hobman 2023). One of the most immediate benefits of PSE for researchers is increased visibility. When scientists share their work through talks, social media, public lectures, or collaborations with schools, museums, or policy groups, it helps build a broader audience for the research outputs. This visibility can lead to new funding opportunities, partnerships, and media coverage (AAAS 2025; Research Councils UK 2020).

Another benefit of PSE is it can enhance the research process itself. Public input on research pathways and the societal challenges that drive them can help identify important problems, refine research questions, design real-world applications, and highlight ethical concerns or community needs that academics may overlook, and lead to more grounded, impactful outcomes. Methods like community based participatory research — where community members are actively involved in research projects — can be particularly powerful in this respect (Amauchi et al. 2022; O'Fallon and Dearry 2002; Balazs and Morello-Frosch 2013). This approach expands the role of communities from recipients of information to collaborators in scientific research.

From a professional standpoint, PSE can enhance a researcher's communication and leadership skills. It builds capacity to explain complex ideas clearly and persuasively, which is valuable not only in PSE contexts but also in teaching, grant writing, and interdisciplinary collaboration. Increasingly, funding bodies and institutions are recognizing and rewarding this work, such as the National Science Foundations' broader impact statements. Ultimately, PSE supports a more open and responsive research culture. It breaks down barriers between academia and society, fostering mutual understanding and shared knowledge. For researchers, it is not just about dissemination of new findings — it is about dialogue, collaboration, and creating a more inclusive, responsible research ecosystem.

Benefits for Broader Publics

PSE with science offers a wide range of benefits for individuals and communities. First, PSE can help increase scientific literacy. By attending talks, visiting science centers, participating in citizen science projects, or following science communicators online, people gain a clearer understanding of scientific concepts, processes, and evidence. This knowledge can help individuals make more informed decisions in everyday life, from understanding health advice to evaluating environmental claims, new products and technologies. More broadly, it can facilitate reciprocal exchange between scientists and communities (Todd et al. 2018).

Second, PSE can act as a forum that encourages critical thinking through focused discussions and dialogue on complex issues with S&T. Participation in dialogue and discussions on S&T can provide tools for people to question misinformation, assess the credibility of sources, and understand the limits and uncertainties of scientific knowledge (Stirling 2008; Stirling, Hayes, and Delborne 2018). In today's world where scientific information is widely available and often contested in multiple venues, these skills can be essential for navigating complex public debates on issues pertaining to S&T.

Third, PSE can give people a voice in scientific research and decision making for new technologies. When the public is invited to share their views, experiences, and concerns, it creates space for more democratic, socially responsible and responsive science.

Public input can guide research priorities, shape ethical frameworks, and ensure that science reflects a broader range of values and perspectives (Susan and Nelson 2022; Douglas and Louson 2024). This is especially important for establishing new norms around who gets to participate in shaping the future of S&T, which is usually only under the purview of those with the power and authority over the direct development of S&T (Owen, Macnaghten, and Stilgoe 2012). Ideally, this aspect of PSE strengthens the relationship between science and society by building trust, transparency, and mutual respect between the scientific community and members of the broader public.

Benefits for Institutional Governance

At a high level, PSE can be a beneficial intervention at multiple points in the governance of scientific research process and the development of new technologies, biotechnologies or otherwise. In this way, PSE plays a crucial role within the framework of responsible research and innovation (RRI). RRI's objective is to work towards more equitable societal outcomes with S&T by generating greater alignment between public interest and the design, development, and decision making with S&T (Owen, Macnaghten, and Stilgoe 2012). RRI calls for engagement with different publics and stakeholders as part of governing S&T which centers PSE activities as an important part of the framework.

RRI has four main principles: anticipation, inclusion, reflexivity, and responsiveness. A*nticipation* refers to practices of foresight applied to identifying and analyzing the potential risks and benefits of S&T (Stilgoe, Owen, and Macnaghten 2013; Guston 2014b; Alvial-Palavicino 2016). Methods for PSE can bring issues of risk and benefit to the table for different groups implicated in upstream development processes and identify specific risks and benefits that apply to specific stakeholder groups and publics (van Grunsven, Stone, and Marin 2024; Barben et al. 2008). Second is the principle of *inclusion,* which refers to diversifying participation in the development and decision making for S&T (Stilgoe, Owen, and Macnaghten 2013). PSE creates opportunities for public audiences to discuss issues with S&T, thereby creating opportunities for more diverse perspectives to impact the development and decision making for S&T (Jansma, Dijkstra, and Jong 2022; Jong, Kupper, and Broerse 2016; Min 2016).

Third is the principle of *reflexivity*, which generally refers to the process of questioning assumptions, values, and roles within the development of S&T (Stilgoe, Owen, and Macnaghten 2013; Steen 2013). PSE can act as an excellent forum for questioning different assumptions that drive technological development, especially for controversial S&T issues (Chilvers 2013)? Lastly is the principle of *responsiveness,* which generally refers to maintaining institutional adaptiveness and flexibility to respond to emerging circumstances and challenges with emerging technologies faced by society (Stilgoe, Owen, and Macnaghten 2013; Di Giulio et al. 2016). PSE can be used to assess how different communities and sectors of society are affected by the downstream impacts of technology development and prepare institutional responses to these potential outcomes accordingly (Groves, Sankar, and Thomas 2018; Delborne et al. 2018).

Misconceptions, Stigmas, and Barriers

There are several misconceptions and stigmas associated with the practices of PSE that can diminish its benefits to communities, researchers, and institutions. Three major issues are: deficit model thinking, the "Sagan Effect," and lack of institutional incentives.

Deficit model thinking: Researchers have argued that a lack of awareness and knowledge of science and innovation can lead to a lack of support in emerging S&T. The logic here is that the more public audiences learn about S&T, the more they understand how it works, the more likely they are to buy into its promises. Through this lens, PSE could be used to ingratiate scientific developments and novel technologies with different public groups (Loureiro, Horta, and Santos 2021). At first this might sound like a good framing, especially given the history of social controversy around different biotechnologies. However, this is a problematic assumption classified as "deficit model" thinking, whereby a lack of understanding of scientific information is assumed to be the reason for public opposition. The expectation is that providing access to more scientific information to public audiences will lead to a change in attitudes. What's missing from the deficit model is the notion of values, interests, and preferences at the center of people's worldviews, which inform perspectives on S&T (Simis et al. 2016; Ahteensuu 2012; Broad and Biltekoff 2023). Ignorance is not necessarily the source of disagreement but rather different underlying values and priorities may result in opposition.

The "Sagan Effect": The "Sagan Effect" refers to the perception that scientists who engage heavily in public outreach or popular science communication are less credible or produce lower-quality research work (Parker 2017; Pagan 2013; Chen, Zhang, and Jin 2023). It is named after the astrophysicist and science communicator Carl Sagan -- who faced skepticism from some in the scientific community and was never recognized for his research nor elected as a member in the National Academies, despite having strong credentials that would qualify him otherwise. The Sagan Effect highlights the tension between expectations of academic professionalism and the need for researchers to engage with publics around emerging S&T. Although this attitude has begun to shift, the Sagan Effect still serves as a cautionary reminder of the institutional and attitudinal challenges scientists can face when stepping beyond the lab to connect with broader audiences (Martinez-Conde 2016).

Lack of institutional incentives for PSE: University and other scientific institutions rarely set up clear goals, support structures, or reward systems for those researchers committed to PSE efforts. PSE activities do not strengthen a publication profile nor directly help researchers obtain grant funding; therefore, it is not conventionally regarded as an important part of tenure and promotion packages at universities, nor considered a high priority for governmental research and decision making (Rose, Markowitz, and Brossard 2020; Cohen 2022; Powell and Colin 2008). As the value proposition of PSE with S&T continues to expand and is socialized to new generations of researchers, these norms could change in the future. As of now, they act as limiting factors on the motivation and capacity for scientists to perform PSE activities.

Guidelines and Methods for Engagement Activities

PSE can be used to involve public audiences on multiple fronts helping to guide SynBio development in ways that align with public values, ethical priorities, and needs of communities. Importantly, scientists can choose from several different topics and audiences to put at the center of their PSE activities. What matters is aligning the relevance of the topic with the audience of interest and asking the right questions to the right audience in the right ways to yield the best results.

SynBio continues to develop real-world applications across multiple sectors that will increasingly impact the lives of many people. Table 1 illustrates some examples of different themes and questions that could serve as subjects for PSE activities related to SynBio. Different researchers might come up with their own specific topics and questions based on their scientific work, and interests in engaging public audiences.

Table 1 — Examples of Themes and Questions for SynBio PSE

Themes	Questions
Public Perceptions	• What are the main concerns people have regarding application of SynBio? • What applications of SynBio would benefit the [specific community] most? • What are the perceived risks of [specific SynBio application]?
Ethical and Policy Concerns	• Is there a moral distinction between "synthetic" and "natural" organisms? (see Matthews et al. 2025) • What is the legal status of synthetic organisms? • How should synthetic organisms be regulated compared to their 'natural' counterparts?
Biosafety and Biosecurity Concerns	• What safeguards (technical, legal, social) can be utilized to prevent misuse of Synbio? • How can regulations and legal agreements be used to protect technologies from theft, weaponization, etc.?
PSE's Use to Combat Climate Change and Environmental Pollution	• What Synbio applications can address carbon emissions challenges? • What are the risks of releasing engineered organisms into the environment?
Impact on Health and Medicine	• How can Synbio help develop more effective, affordable medical treatments? • What are the ethical issues for applying Synbio within human bodies?

Source: Authors' analysis; Matthews et al. 2025

Audiences

Often, the scientific community designates certain groups as directly involved in scientific research (i.e., scientists, funders, university administrators, etc.). Those external to the processes of research, may be referred to in general terms such as "the public" or even just as "society." The boundary between external social groups "in society" and people involved in scientific research is somewhat artificial, given that research scientists themselves are also part of society. Therefore, it is helpful to think of this boundary from an instrumental and experiential perspective, based on who has a direct hand and experience in working with scientific processes, and who is going to use, be impacted by, or have a direct stake in the outcomes of S&T.

The boundary between scientists and "the public" can be broken down in other helpful ways. The first important point is to first do away with broad notions of "the public." As many authors have pointed out in the PSE literature, there is no one de facto representation of "the public" (Stirling 2008; Krzywoszynska et al. 2018; Macnaghten and Chilvers 2014; Felt and Fochler 2010). The collection of citizens and communities that make up society are an extremely diverse, heterogeneous group. To refer to them all as simply "the public" does a disservice to this heterogeneity and reinforces harmful power dynamics and assumptions about different communities' relationships with S&T (Simis et al. 2016; Frow 2020). Moving from ideas of "the public" to thinking in terms of many different publics is a critically important conceptual move for researchers who want to design PSE activities.

Another boundary to be aware of is the one constructed between ideas of what constitutes a difference between a member of the "public" and who is considered a "stakeholder". Some authors have argued that public engagement specifically applies to public groups that don't have a direct stake or involvement in the development of new technologies (e.g. interested or disinterested publics). Stakeholder engagement, therefore, are activities that are usually designated for engaging those with a vested professional interest such as scientists, developers, and funders (NASEM 2026). However, it becomes quite tricky to define exactly what qualifies as a valid enough vested interest or direct involvement in S&T, and thus, who qualifies as a stakeholder versus a member of the public (Reed et al. 2009; 2018). One could also argue that stakeholders themselves are also members of the public at large, which further complicates this label.

For the purposes of this paper, we want to be all-encompassing in our exploration of the practices and people who could be involved in PSE activities. Therefore, we will not authoritatively declare who is and is not a stakeholder versus a member of the public. Instead, we offer several broad categories that can help start delineating the types of groups that one could identify as potential audiences for PSE activities. They include affected communities, interested and disinterested publics, developers, scientific expertise, and policy makers. To recognize each of these broad categories acknowledges that different groups have a multitude of associations with emerging technologies, and therefore there are multiple target audiences for which engagement activities can be designed (see Table 2).

These categories begin to emphasize the heterogeneity of the different groups implicated in the development of emerging technologies. However, it is important to remember that these monikers do not represent an exhaustive list, but broad categories. Each category itself can be further broken down into more specific sub-groups and into even more specific social identities and communities within those subgroups. For example, interested publics could be broken down further into groups that are supportive of S&T and those who are opposed. Affected communities could be delineated into groups that will likely experience benefits from S&T innovations and those who will not. In addition, categories can sometimes overlap with one another. For example, a member of an affected community may also be a developer working for a local start-up or a policy maker representing a specific community. Likewise, scientific experts could also be considered a member of the "interested public" if their field overlaps with the S&T topic of interest but are not directly involved in development. Therefore, while categories are a useful heuristic device for targeting audiences, it's important to recognize the nuances and overlaps between them so as not to oversimplify people's communities and social identities.

Table 2 — Broad Categories of Audiences for PSE

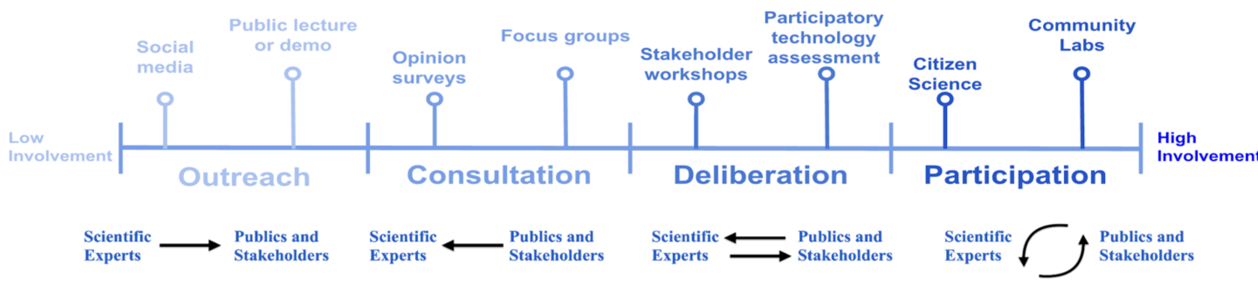
Audience	Description
Affected Communities	People who are impacted by technologies but not involved in their development
Interested Publics	Public audiences who take a focused interest in issues surrounding the development and distribution of emerging technologies but are not directly involved in those processes; can include individuals or groups (e.g. civil society organizations)
Disinterested Publics	Public audiences who are either not interested or not aware of issues related to the development of emerging technologies
Developers	Individuals and/or organizations directly involved in the development and distribution of emerging technologies
Scientific Experts	Individuals or organizations who have specialized training in the knowledge fields most relevant to the S&T
Policymakers and/or Elected Officials	Individuals or groups who may have a role in making decisions concerning the governance of science and technology

Source: Authors' analysis.

Methods for PSE

Different methods for PSE can be applied to engage broader publics, specific communities, and different stakeholder groups, albeit with some nuances. Content of an engagement exercise for expert stakeholders may be curated differently than an exercise aimed at affected communities or broader public audiences. Questions might be more narrowly directed at specific issues that require specialized expertise for stakeholders and developers, whereas affected communities might be more concerned with how new technologies impact their socio-material realities, livelihoods, environments, etc. Whatever the goals and objectives of may be, there are four main categories of PSE — outreach, consultation, deliberation, and participation — each with different methods best fit for one's unique purpose (see Figure 1).

Figure 1 — Spectrum of Possible Engagement Activities Across the Four Broad Categories: Outreach, Consultation, Deliberation, and Participation



Source: Authors' analysis.
Note: Nodes indicate examples of specific methods belonging to each category. Categories are situated on a spectrum from lowest to highest direct involvement in research activities and information exchange between experts and publics are characterized for each category.

Education and Outreach

Education and outreach refer to the practice of spreading knowledge, information, and awareness to connect wider publics with the processes and outcomes of research. This includes STEM education efforts in K-12 sciences courses but extends beyond this conventional education space to more public venues. Education and outreach methods are characterized by a one-way flow of information from experts to stakeholders and publics. Importantly, a common motivation for education and outreach is to connect a specific target audience with the sciences and make an impact on either knowledge or attitudes towards that science. Goals of education and outreach could include informing public audiences of different research advancements, socializing audiences to new ideas and technologies, generating interest in a scientific field, or skills-building in a particular scientific practice (Clark et al. 2016; Zielinski; Jimenez et al. 2022; Novossiolova et al. 2021).

Examples of public education and outreach beyond the classroom include social media, public lectures and science festivals.

- **Social media:** Scientists have made use of social media platforms (e.g., Facebook, X, Instagram, TikTok, Bluesky) as a tool to share updates on their research and contribute to public discussions on issues pertaining their field and research interests through videos, text, and memes. Professional societies have embraced the use of social media for knowledge translation, dissemination, and education purposes across multiple disciplines, including the biological sciences (ASCB 2025; McClain and Neeley 2014).

- **Public lectures and demonstrations:** Researchers can give lectures and can even perform interactive experiments or demos of their research work in public venues accessible in person or through multimedia platforms. The now famous TedTalk method has been popularized over the years, but researchers can also participate in more local venues such as museums, K-12 schools, libraries, community centers, or even open their own research facility for an "open house."

- **Museums and science festivals:** These platforms provide opportunities for interactive learning, where visitors can explore topics in a fun and educational way through a collection of exhibits and live demonstrations. Museums and festivals are centered in specific locations and take on attributes of the local community. This helps bridge the gap between local scientists and local citizens through a forum of fun and exploration while also offering a kind of educational science-tourism to travelers.

Box 1— Case Study #1

The Philadelphia Science Festival
The Philadelphia Science Festival was an annual event organized by the Ben Franklin Institute that ran from 2011–2019 bringing together local scientists, educators, and community members to celebrate science through a series of engaging activities, lectures, demonstrations, and hands-on experiences (Visit Philadelphia 2020). Spanning over several days, the festival included events at museums, schools, libraries, and public spaces, aiming to make science accessible to people of all ages and backgrounds. Unfortunately, in 2020 with the advent of COVID-19 lockdown, the festival was cancelled and has since failed to be revived (93.3 WMMR 2020). The success of the Philadelphia Science Festival was in its ability to attract thousands of Philadelphia locals and out-of-town visitors to its grounds every year with a massive array of live events. Free admission was provided for all through an amassing of hundreds of sponsors and partnerships, including local universities like University of Pennsylvania, Drexel University, and Temple University. By connecting the public with scientific professionals and fostering curiosity, the festival encourages lifelong learning and promotes the importance of science in daily life and building stronger connections between the scientific community and residents. However, festivals like this require immense planning and resources to promote, organize, and facilitate. A central organizing institution, strong leadership team, available funds, and supportive city ordinances all need to align to make these large-scale events successful. The Philadelphia example also shows that momentum and continuity between organizers, partnerships, and expectant audience are challenging to establish, and harder to rekindle once derailed. But if established, these large-scale events can be enormously successful.

Challenges and limitations of education and outreach: Education and outreach can be a cost effective and straightforward option for scientists in working laboratories. However, there are major challenges and limitations with this approach. First, a one-way information stream leaves little space for experts to consider the viewpoints and values of public audiences. As such, education and outreach can tend to remain ignorant of the concerns of public audiences by failing to connect with their key concerns, hopes, and motivations. This can lead to deficit model thinking regarding the impact of the work, where if scientists lecture enough, they can change minds and hearts without regard to other values and interests. In addition, scientific experts can project unclear information or perhaps experience backlash from public audiences who do not like what they have to say. Further, sometimes projects do very little follow up to evaluate impacts, which leaves practitioners with little understanding of what the activities accomplished

(Andrews et al. 2005; Woitowich et al. 2022; NASEM 2017; Biermann, Banse, and Taddicken 2025).

Consultation

Consultation refers to the practice of inviting groups of stakeholders or publics to share what they think about a particular branch of scientific research or technology. Consultation is characterized by a one-way flow of information from stakeholders and publics to research experts. A common motivation for conducting a consultation is to understand the different perspectives, knowledge, and/or concerns different groups have towards a scientific field, emerging technology, or controversial issue in science and society. The goals of consultation are usually tied to getting a sense of the attitudes of a specific target group towards a scientific issue or technology of concern. Often, capturing the attitudes of a subsection of a particular population can suggest to researchers the degree to which a particular population either supports or opposes certain scientific and technological advances, and what kinds of worldviews and values that underwrite those attitudes. Another important goal for consultation is gathering knowledge and perspectives for the purposes of assessing research pathways and outcomes, solving a problem, or impacting the decisions made in the governance of S&T.

A common method for consultation style engagement is the use of surveys and questionnaires. However, other methods include the use of focus groups, town hall meetings. Some citizen science approaches also make use of consultation. These methods are effective for accessing the perspectives of many kinds of public audiences, as they can be deployed in a relatively standard fashion across contexts. Large data sets collected through methods like surveys and questionnaires can further be analyzed by statistical means to generate insights on public attitudes towards S&T. Such results can be useful for understanding the status of public support and opposition towards new technologies, especially for ones that are more controversial than others (Akin et al. 2017; Jones et al. 2019; Jordan et al. 2022; Grieger et al. 2022; MacDonald et al. 2020).

Challenges and limitations of consultation methods: The main challenge for consultation is the dynamic of one-way information exchange provides little feedback benefit to those being consulted. Problematic assumptions can also sometimes be embedded in the materials used to engage audiences (i.e., surveys and questionnaires). For example, respondents might not be given rich enough context to fully engage with the information they are presented, thus biasing responses. Lastly, the group being consulted has little to no power to impact decision making or influence research processes. Consequently, results may or may not be incorporated into research processes and decision making at the discretion of the research team in charge of the project. This runs the risk of becoming “helicopter research,” where researchers come into communities to collect data, but neglect to meaningfully incorporate community values, needs, and experiences into research or policy outputs (Lambert et al. 2024).

Box 2 — Case Study #2

Public Attitudes Towards SynBio
Researchers can gather large data sets on public attitudes using quantitative survey methodologies like the authors in Akin et al., who performed a public attitudes study on how perspectives on SynBio compared to other emerging technology categories. Using a nationally representative study population, the researchers wanted to know how informed the American public was on issues pertaining to SynBio, and whether they held concerns over SynBio that were substantively different than other emerging technology issues pertaining to fields such as nanotechnology and climate change. Surveys were distributed and collected electronically over a period of 2 years in 2012 and 2014. Results indicated that the respondents were much less informed about SynBio compared to other technology areas, and that they held some unique moral and ethical concerns over SynBio (Akin et al. 2017). While these opinion surveys were mainly used for basic research purposes, outputs of the work could be used to inform future decision making and research agendas. The authors' conclusions speak to broader issues of religiosity, deference to science, and the relationship between public trust and science. The method could be translated to other project contexts focused on policy making or product development.

Deliberation

Deliberation refers to the practice of exchanging perspectives and knowledge through discussion and debate on a mutually held issue of concern within S&T. Deliberation situates participants into a two-way, face to face, real-time discursive exchange of ideas and perspectives with one another, and sometimes scientific experts. Deliberation can be designed to include industry stakeholders, publics, and scientific experts, non-government organizations (NGOs), and policymakers. The goal of deliberation, like consultation, can also be directed towards understanding public and stakeholder attitudes towards S&T. However, a more robust use of deliberation is to try and enhance decision-making and policy discussions around S&T by incorporating multiple viewpoints into a decision-making process and working towards a consensus. Deliberation does not necessarily always need to reach a consensus. Instead, deliberation can also be useful for generating a diverse array of ideas and exchanges on a topic, where some agreement and common ground is forged while disagreements are uncovered and explored (Min 2016; Burgess 2014; Burgess, O'Doherty, and Secko 2008; Chilvers 2008; Mansbridge 2015).

Methods for deliberation include a spectrum of different approaches. For the purposes of this paper, we can divide them into two broad areas: public deliberation and expert-stakeholder deliberation. ***Public deliberation*** is explicitly focused on building deliberative processes centered on discussions between members of the public outside of scientific expertise or stakeholder groups. Approaches usually involve more open, inclusive discussions where people with different kinds of knowledge come together to discuss issues on emerging S&T. Public deliberation is a form of active engagement utilizing structured dialogues that require participants to listen and consider the viewpoints of others in the room to perhaps chart out common ground across perspectives, or at least map out what different community/publics perspectives are and where they intersect. Outcomes can be used to guide policy decisions, scientists' priorities and motivations for research, and even product development and regulations (Beekman and Brom 2007; Goold et al. 2012; Hagendijk and Irwin 2006; Bohman 2003).

Expert-stakeholder deliberation involves a combination of subject matter experts and decision-makers that have a direct professional role in S&T fields. In SynBio, these groups include scientists, ethicists, policymakers, industry leaders, and other specialized professionals. Deliberative discussions often focus on topics such as technical feasibility, safety standards, regulatory frameworks, and the broader societal implications of a technology. Outcomes can help shape research funding priorities, regulations, industry practices, and public policy decisions. Expert-stakeholder deliberations can be very useful for assembling different kinds of experts to discuss nuances of more narrow, focused issues compared to broader engagement activities (Conduct et al. 2016; Taitingfong and Ullah 2021; Barnhill-Dilling, Kokotovich, and Delborne 2021; Farooque et al. 2019).

Box 3 — Case Study #3

Transgenic American Chestnut Tree

In the mid-2000s, researchers at State University of New York College of Environmental Science and Forestry inserted an oxalate oxidase transgene into the genome of American chestnut that conferred blight resistance in laboratory testing and field trials. This transgenic chestnut was the first of its kind; a genetically-engineered (GE) tree designed to help restore the once widespread species back into its native Appalachian range. Many questions regarding the safety, efficacy, regulations, and social implications of developing and implementing this GE chestnut (Powell 2016).

In 2018 researchers from North Carolina State University organized a two-day deliberative discussion on the GE chestnut to discuss issues of progress, challenges, and complexities related to the GE chestnut tree at each phase. Workshop participants all had background expertise and experience with chestnut trees including science; restoration and/or conservation; commercial forestry; and environmental advocacy. Discussion sessions organized participants around the concept of “decision phases” meant to symbolize the lifecycle of emerging technologies. Workshop participants worked on generating a framework for how PSE could contribute to decision-making in each phase, and to generate some concrete scenarios for designing PSE activities. This workshop demonstrates an example of how expert stakeholder deliberation can be designed, facilitated, and what kind of outputs it can produce for an emerging technology (Delborne et al. 2018).

Box 4 — Case Study #4

NASA Asteroid Initiative
In 2015, Arizona State University's Center for Science, Policy, and Outcomes in partnership with the Expert & Citizen Assessment of Science and Technology group organized and facilitated a large-scale participatory technology assessment (pTA) project in collaboration with NASA. The focus was the NASA asteroid initiative, a program designed to investigate options for expanding infrastructure to detect, track, and potentially destroy asteroids on trajectory to collide with earth. Citizens discussed the priorities and vision of the project and were asked to share their perspectives on what was most important to them in relation to the project. Organizers developed different discussion sessions focused on these questions like; "What would an effective detection system look like? Should we develop capacity to redirect asteroids and capture them for scientific study? What might these capabilities mean for future space exploration?" (Tomblin et al. 2015; Tomblin et al. 2017). The project brought together 186 participants two different sessions. Participants heavily favored developing certain space-based observational tactics alongside extending the existing ground-network approach. Another important aspect of developing this system for the participants was international collaboration between space agencies, and importantly, not allowing private entities to take on a meaningful leadership role. Results from these discussions were translated into recommendations for NASA to consider as they continued developing the asteroid defense program. The Asteroid Initiative pTA example shows that public deliberation can be an effective means of bringing multiple publics into discussions on issues related to emerging S&T development and policy. Unfortunately, pTA is a far less commonly applied method in the United States than it is in other parts of the world, such as Europe. pTA is highly effective form of public deliberation on S&T topics, but it does require more dedicated and reliable funding, resources, and time from researchers, facilitators, and other external partners (Farooque and Kessler 2023).

Challenges and limitations to deliberation: Sometimes, the aspiration of organizing deliberation is to use the outputs to inform a decision-making process, or to incorporate them into some type of policy-relevant S&T discussion. This has proved difficult to achieve, as translating outputs to meaningful impacts in policymaking, research, or product development is not straightforward (Kuzma 2021; Kokotovich et al. 2020). In addition, deliberation takes in-person time, resources, and careful planning to conduct effectively and reach valid outcomes. One must be thoughtful during the participant recruitment process - which is often biased and targeted by necessity — and when setting up a level playing field for dialogue, so powerful voices don't dominate discussions. Lastly, while consensus is desirable during deliberation, it's important to make space for dissenting viewpoints to be heard and acknowledged as they may reflect important perspectives that are not well-represented in the room (Valkenburg 2020; Bouwel and Oudheusden 2017). This may require some flexibility on the planning end in recognizing that the problems and assumptions used by organizers to set up discussions may encounter push-back during deliberations (Powell et al. 2011; Betten, Broerse, and Kupper 2018; Bauer and Bogner 2020).

Participation

Participation refers to the direct involvement of publics and/or stakeholders in the research process, either in problem identification and study design phases through data collection, analysis, and reporting. Participation is unique in that the goal is to bring publics and stakeholders into direct collaboration with researchers. This opens possibilities for publics and stakeholders to contribute directly to research project outputs and earn credibility for these contributions.

The two broad categories of participatory methods include citizen science and community-based participatory research. ***Citizen science*** is a collaborative approach where everyday people, often without formal scientific training, contribute to research by collecting data, making observations, or even analyzing results. This broad and inclusive model allows scientists to gather large-scale data across diverse locations, enhancing the speed and scope of research projects. Citizen science spans fields like ecology, astronomy, and environmental monitoring, empowering individuals to engage with and often contribute to scientific discovery while also raising awareness of important issues (Bonney et al. 2009; Kimura and Kinchy 2016; Hecker et al. 2018).

Community-based participatory research (CBPR) is an approach where researchers and community members work together as equal partners throughout the entire research process. This collaborative method ensures that the community's needs, knowledge, and values are central to the study, fostering mutual trust and respect. CBPR aims to address local issues while promoting social change, often in fields like public health, environmental justice, and education. CBPR's approach is to create more relevant and sustainable solutions that benefit the community directly. An important characteristic of CBPR is that research and its data outputs are usually owned primarily by the researchers in charge of the project and not the communities involved, although results are often shared and distributed to participating communities (Amauchi et al. 2022; O'Fallon and Dearry 2002; Balazs and Morello-Frosch 2013; May et al. 2021; Lee et al. 2024). Extending from CBPR is community-owned and managed research (COMR), a research approach where the community takes full ownership of the research process from identifying priorities to designing, conducting, and managing the study. In this model, the community dictates the research priorities and agenda, and has control over how data is collected, analyzed, and used. This approach empowers communities by ensuring that the research reflects their values and needs, fosters self-determination, and promotes long-term sustainability. COMR is particularly effective in addressing local issues and creating solutions that are both culturally relevant and directly beneficial to the community (Lee et al. 2024; Heaney, Wilson, and Wilson 2007; Heaney et al. 2011).

Challenges and limitations to participatory methods: Participation methods offer the highest level of involvement in research for the public and stakeholders. However, this often requires greater time and resource commitments than other methods given the sustained engagement with publics and stakeholders that is required for training and data collection efforts. In addition, ethical issues often centered on ownership and sharing of data, and credibility for research. Lastly, sometimes the legitimacy of a citizen science, CBPR, or COMR project is called into question by the research community because they involve the participation of non-experts. Researchers who have engaged in these projects regularly push back against this critique that data gathered and analyzed in citizen science, CPBR, or COMR is just as robust and rigorous — if not more so — than conventional scientific research methods (Amauchi et al. 2022; Rasmussen and Cooper 2019).

Box 5 — Case Study #5

eBird Project Crowdsourcing Citizen Science
Cornell's eBird project is a global, citizen science initiative that allows birdwatchers of all skill levels to record and share their bird observations online. Managed by the Cornell Lab of Ornithology, eBird collects millions of bird sightings each year, creating one of the largest biodiversity databases in the world. Using a simple smart phone app, eBird allows amateur bird enthusiasts to capture image of local bird sightings and report those sightings to a national database. Each year, thousands of entries become thousands of data points that contribute to research on topics like bird behaviors, population levels, migration patterns, and changes in species distributions over time (Schader 2024; Glaves 2024). The eBird project is a great example of crowdsourcing citizen science, as it is one of the longest running projects that utilizes data collected from non-scientists as the basis for scientific study. Rapid transmission and massive accumulation of data allows scientists to actively track migration patterns and population levels of different species at a scale not before possible. According to eBird, the crowd-sourced database has been used to generate over 900 scientific publications on different ornithological topics (Rosenblatt et al. 2022; Bianchini and Tozer 2023; Bonney 2021).

Box 6 — Case Study #6

Genspace Community Bio Lab
Genspace is the world's first community biology laboratory. Located in Sunset Park, Brooklyn, NY, and founded in 2009, Genspace provides a multidimensional collaborative space where individuals from diverse backgrounds can engage in hands-on life sciences experiments. The lab is outfitted with basic equipment found in most professional research labs, including microscopes, DNA sequencers, and PCR machines within a Biosafety Level 1-compliant facility. Genspace invites artists, students, hobbyists, and others to become members of the space. Members can participate in educational programs, community-driven research projects, and training programs which prepare individuals for careers in biotechnology. Genspace's goal is to create opportunities for community members and students to participate in biotechnological innovation, and to build greater inclusivity in the life sciences by making scientific exploration accessible to all (Genspace 2025a; 2025b; Muindi 2024). While Genspace does a lot of educational and outreach programming, some of what they do can also be considered community-based participatory research. Laboratory research projects that are pursued by local hobbyists or aspiring startups are housed within Genspace, but the research projects are completely managed by the member conducting that research. Genspace also facilitates community projects, which are open-source research and design projects organized and conducted across different members of Genspace. While community projects receive support from Genspace staff, the research questions, methods, and outputs are managed by the community members.

PSE Opportunities in SynBio

Synthetic biology holds great promise for new technologies, therapies and scientific advancement. However, without public input and acceptance it will not be able to live up to it's potential. Products might be feared by the public and left unused. Or they might end up not being appropriate for the communities they were built to serve. Products might also exacerbate existing inequities. Therefore, it is vital for researchers in SynBio to conduct PSE throughout the development process. This includes early stages of research and knowledge generating phases; during the applied phase where knowledge is being used to develop products; and at the development phase when products are being tested to determine their safety and effectiveness.

We suggest three different avenues for moving forward to ensure PSE is adequately linked to SynBio and used to develop new technologies.

Engage in Consistent Outreach Activities in Local Communities

As one of the less resource intensive and easily managed PSE activities, scientists should build some form of outreach activity connected to their work. One of the most practical first steps is to start by identifying an audience and platform based on the person's skills and preferences. Some scientists are more effective writers, while other prefer direct discussions or lectures. Whether making use of social media, doing a live demonstration with students, or presenting to policymakers, local community members, or broader publics, effective communication begins with understanding the target audiences' knowledge, interests, and concerns. Effective education, outreach, and communication should:

- Use clear, jargon-free language and relatable examples to make your work more accessible;
- Invoke storytelling. Personalizing the outreach by discussing the key features of your personal journey in science and how your research came into being can make your message more memorable and engaging;
- Partner with educators, science communicators, or outreach organizations. This can also help refine your approach and broaden your reach; and
- Approach audiences with humility and curiosity by inviting feedback from your audience and listening to what they have to say.

Though these methods set up mainly a one-way exchange, this can always be displaced in the moment by welcoming feedback and envisioning the experience as a two-way exchange.

Furthermore, outreach should be regular and sustainable, not just a one-time effort. To make this happen, partnerships are key for building trust and granting access to different community spaces, but also to share labor and costs of conducting these activities. Some institutions have already set up programs for education and outreach that can be partnered with. For example, Rice University has Baker Institute's Civic Scientist program and Rice's Office of STEM Engagement Programs (Baker Institute). Programs like these are invaluable for creating and sustaining engagement activities over time, and can provide practical advice and support for researchers without formal training in science communication. In addition, local schools, museums, and community groups can be excellent partners for developing regular, low-cost activities.

Outreach opportunities can also be used to train students and postdocs in science communication by incorporating their work into outreach activities. Digital platforms like blogs, podcasts, or social media are also effective places to share information and spread awareness of a research, especially because they can be done individually at low cost. Some institutions might even have audio and visual resources set up for researchers to make use of in doing digital education and outreach activities. Building these norms into the outset of burgeoning SynBio research programs can help establish an institutional culture of incentivizing and rewarding education and outreach efforts for SynBio.

Consult With Stakeholders on Future Risks, Benefits, and Development Pathways

Scientific research programs in SynBio would benefit immensely from regular consultation with stakeholders on issues pertaining to risk, benefits, social and ethical challenges, and barriers to pathways of development and deployment. Conferences and workshops have long served as a method for bringing together members of the professional scientific community to discuss cross-cutting challenges in scientific fields, and these approaches can (and have) expanded to include broader stakeholder groups. A stakeholder workshop, for example, that invites multiple representatives from government, academia, and industry, can be very useful for discussing broad issues pertaining to policy, commercialization, and social implications of emerging SynBio. Scientists that participate in these events develop a greater knowledge and understanding of how their work translates beyond academia, building more integrated networks with those who work on SynBio in other professional contexts and helping drive more thoughtful products that could better integrate into society. While these events take significant time and effort to organize effectively, they can be immensely rewarding.

Other methods to consult stakeholders include working with other scholars to develop and conduct stakeholder surveys and interviews. Having a robust list of stakeholders with different perspectives/stakes across multiple sectors on SynBio research will produce rich results and understanding of concerns and challenges. Stakeholders may be more accessible to university researchers than members of broader publics, especially if they are part of organizations whose mission and interest is aligned and bought in to SynBio. It is vital for researchers to do this consultative work, especially for a field like SynBio which promises several transformative innovations in the biomedical, manufacturing, and energy production industries.

Build PSE Into Research Projects

Scientists should consider integrating PSE into all future research projects. This can start by adding PSE to grants (i.e., “broader impacts” sections), broader departmental activities, or within university community priorities to provide both structure and funding. These activities should be a collaboration between scientists and other scholars interested or engaged in PSE, such as social scientists, ethicists and policy scholars as well as experienced science communicators. By combining their strengths, they can create more effective, inclusive, and impactful communication. Scientists are vital to this effort by contribute subject-matter expertise, while their collaborators can offer insights into public perception, cultural and political context, and communication strategies.

Every grant focused on developing a new application of SynBio provides an opportunity for PSE research work. Scientists can work with other experts to make this come to fruition by designing projects aimed at engaging members of the publics, experts, policymakers, or industry on important societal issues or implications pertaining to what is being developed in their laboratories. Results can benefit research laboratories and broader governance and policymaking for SynBio moving forward. Together, they can design PSE that is technically accurate and robust but also responsive to community values, concerns, and ways of knowing. This multidisciplinary approach can help develop mutual understanding and trust between natural scientists and other scholars while also ensuring that PSE efforts are both scientifically sound and socially meaningful.

An effective way to build collaboration around PSE is for research scientists to recruit and work with collaborators when applying for research grants. These can take the form of mutually conceived research projects or multidisciplinary approaches to emerging technology areas. For example, scientists might design a project that focuses on the technical development of an engineering platform while their collaborators might investigate some of the social and policy implications of applying that platform in society. Investigators can come together around PSE to combine insights and questions from their separate projects, asking publics or stakeholders to engage with both technical and social dimensions of SynBio.

Conclusion

As the field of SynBio continues to evolve, there will be ample opportunities to include diverse societal groups in discussions about scientific research and development to ensure that public values and interests are integrated into SynBio innovations. This paper provides an introductory toolkit for researcher and developers to think through how they can enhance their research and development programs with public and stakeholder engagement (PSE). We have outlined the need for PSE; identified its benefits for researchers, the broader public, and institutional governance, addressed common misconceptions and barriers to effective engagement, and included some starter recommendations for building in PSE as a regular part of research and development programs.

We emphasize that this paper is only an introductory resource, and not a comprehensive how-to guide. We encourage our readers to explore the many citations and references across all sections to further deepen their understanding and interest in PSE. Researchers and developers are in the most favorable position to normalize the value and contributions of PSE to SynBio, and we hope this toolkit serves as a valuable resource for researchers seeking to enhance PSE in SynBio to ensure that scientific advancements align with societal values and needs.

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