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PERSPECTIVE

Public Engagement with Biotechnology Inside and Outside the Classroom: Community-Focused Approaches

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Abstract

Biotechnology offers vast benefits to the environment, animals, and human health, and contributes to improving socioeconomic conditions for the public. However, biotechnology innovations continue to trigger public concern and opposition over their potential social, health, and ecological risks. There is an opportunity to increase knowledge and acceptance of biotechnology through engagement, education, and community participation. In this perspective, we highlight crucial factors that shape the public perception of biotechnology and present opportunities for scientists to effectively communicate their ideas while engaging with local and global communities. Initiatives that seek to involve communities in design, development, and adoption processes are crucial for the successful implementation of biotechnology-based solutions.

A primary goal of biotechnology ideas and innovation is to translate biotechnology as products or services for society. Yet, many of these technologies fail to reach their target audience and fall into the translational gap also known as the "the valley of death."[1] Barriers against effective translation include securing funding on high upfront costs of research and development,[2] and inadequate training of the workforce.[3,4] Beyond these scientific limitations, a multitude of socioeconomic factors and low awareness and understanding of biotechnology are additional barriers that impact acceptance by target end users.[5–8]

For example, poor public perception of genetically modified (GM) crops is common in Latin America despite efforts to improve public perception of agricultural biotechnology through print materials and town meetings.[9] Acceptance of agricultural biotechnology is influenced by perceived perception of risks and benefits of GM crops. Poor perception may lead to confusion, misunderstanding, and ignorance of information that impedes an individual's ability to make informed decisions on how biotechnology should be used.[10]

Key stakeholders involved in developing and translating these technologies include research institutions, governments and regulatory bodies, health care industries, agricultural industries, and the nonprofit sector.[11] The translation or implementation of biotechnology in society requires these stakeholders to effectively inform end users on its risks and benefits. This process involves engaging a variety of audiences to facilitate public awareness and understanding of biotechnology before and during its implementation. In this perspective, we highlight crucial factors that shape the public perception of biotechnology and present opportunities for scientists to effectively communicate their ideas in close partnership with key community representatives (Fig. 1).

Critical Factors That Influence Public Perception of Biotechnology

Trust

Trust is a fundamental tenet of the scientific enterprise. The Oxford Dictionary defines trust as a "firm belief in the reliability, truth, ability, or strength of someone or something." Trust is crucial both for the process of developing knowledge and for the public understanding of science and adoption of new technologies.[12] This is particularly true in the field of biotechnology, which includes topics of high public visibility and debate such as GM foods and stem cells.

A 2019 survey of Chinese consumers found that trust in GM scientists has a positive impact on acceptance of such foods.[13] More recently, trust in domestic scientists and health care professionals and the vaccine development process is strongly

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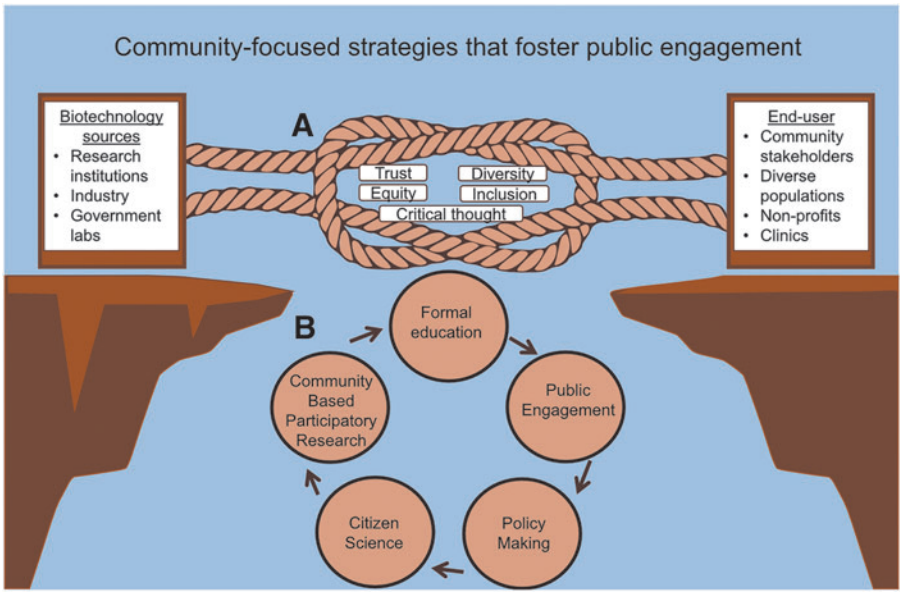

FIG. 1. Representation of the gap between biotechnology sources and end users with opportunities to strengthen implementation by understanding.

(A) Critical factors influencing public perception of biotechnology.

(B) Community-driven strategies within the spheres of communication of biotechnology that bridge the gap.

tied to COVID-19 vaccine acceptance in several countries including the United States, Canada, Russia, Germany, China, Indonesia, Thailand, Turkey, and Vietnam.[14,15]

Public trust in science and biotechnology is affected by a variety of factors. For example, studies from 2015 and 2016 showed that trust in GM foods increased with increasing science knowledge in the United States.[16] The commercialization of biotechnology also leads to unintended consequences for mistrust due to perceptions of funding sources. An Australian survey found decreased trust in privately funded stem cell scientists compared with their publicly funded counterparts with no significant differences in perceived competence.[17] Public trust also varies by application. Global support for new technologies to help women become pregnant averages 73% of respondents, whereas research on animal cloning is opposed in most populations.[18]

Nonetheless, trust levels can change. In 2020, Americans' attitudes and trust in the scientific community increased by an average of 10% from 2019[19] likely due to the global pandemic and the frequency with which science has been the focus of news and treatments for COVID-19. In addition, a recent study by 3M revealed that 83% of the audience surveyed across 17 countries wants to hear more from scientists about their work.[20] Thus, there is a need for biotechnologists across academic, public, and private sectors and all subfields to engage with the communities they seek to impact. Relationship building is crucial for the development of trust and effective interactions between stakeholders.

Representation, diversity, and inclusion

Distrust in biotechnology is also fueled by past and current practices that harm populations historically excluded from the scientific mainstream. Examples of these damaging practices include the lack of informed consent in the collection of HeLa cells,[21] unethical pharmaceutical trial designs in the Global South,[22] and the prescription of crop programs designed in the Global North for implementation in other parts of the world without local input.[23] In addition, the current landscape of participation in biotechnology does not represent many communities. In the United States, 75% of biotech management positions are occupied by individuals who identify as non-Hispanic white compared with 16.5% Asian, 3.8% Hispanic/Latino, and 3.1% black/African American.[24]

At a global scale, countries in Latin America and Africa collectively hold <0.5% of the value share of the health biotechnology sector worldwide with the United States holding 58.8% of the value share.[25] Yet, biotechnology has the potential to solve some of the biggest problems that contribute to local and global inequities (e.g., food security, vitamin deficiencies, vector-borne disease prevention, climate readiness). Diversity of experiences and perspectives is crucial for innovation.[26] Thus, inclusive engagement strategies, such as those described in this perspective, are imperative to increase the participation of diverse communities in the development, implementation, and adoption of biotechnology.

Critical thought

The COVID-19 vaccine-related infodemic revealed the particular vulnerability of biotechnology to the spread of misinformation across the globe.[27–29] The absence of critical thinking poses a major threat to the development, implementation, and appropriation of scientific knowledge and technology. Critical

thinking, the process of connecting "thinking and reasoning with the outcome of a decision or action,"[30] allows the individual to find relevant information, consider the sources and data, and make an informed decision based on reliable data. Although many factors contribute to misinformation (e.g., education level, age, pre-existing beliefs, political polarization),[31,32] the ability to think critically plays a crucial role in enabling individuals to distinguish between science-based data and "fake news."[33]

O'Brien et al recently demonstrated that blind trust in science without engaging in critical thinking made study participants more susceptible to pseudoscience and false claims.[34] In contrast, reminding participants about the importance of critical analysis reduced belief in these claims. Priming critical thinking by providing guidelines to analyze news stories is also an effective strategy to mitigate the impact of misinformation on social media.[35] Similarly, teaching audiences to identify logical flaws and misleading rhetorical techniques in a game format has been demonstrated to effectively "inoculate" players against misinformation on climate change.[36] Thus, strategies that boost, prime, and support reasoning and analytical skills in both formal[37,38] and informal[39] engagement settings are crucial for the future of societies.

Improving Understanding Through Spheres of Communication

Primary and secondary education

Today's world faces wicked challenges that must be addressed in interdisciplinary teams; designing solutions to pressing problems such as food scarcity, waste management, climate change, and emerging infectious diseases requires expertise in multiple fields. Thus, an appropriate science curriculum for the 21st century needs to address scientific topics in an interdisciplinary way.[40] Traditional science teaching methodologies are teacher centered and lack student-centered learning activities that encourage critical thinking discussions similar to scientists' approach in building arguments for scientific claims.[41]

New teaching strategies that combine design thinking and science, technology, engineering, and math (STEM) disciplines guide students to define problems within their contexts.[42] With these tools, students explore needs, identify human and nonhuman users, and search for the solution that is most appropriate to their context.

Biodesign in High Schools,[43] an international 2021 Index Award winner for the Play and Learning category, is a pedagogical approach that guides students to define problems or opportunities within the framework of the sustainable development goals and provides the tools to ideate solutions that are context based. One aspect of this pedagogical approach is to create opportunities to think about a better and fairer future. Students have worked on projects to clean contaminated water, process food waste, and find sustainable alternatives to existing clothing textiles, to name a few examples. By teaching and empowering students to build ethically responsible solutions they can help decrease negative impacts on the environment and communities, pursue fulfilling careers, and learn how to face and handle challenges ahead.

The biodesign methodology allows students to learn how to Incorporate cutting-edge biotechnologies into solutions to real and contextualized problems. Teachers instructing on biodesign may not be expected to be primary experts in the fundamental development and design of such biotechnologies. Yet, teachers are uniquely capable of guiding students in contextualizing biotechnology and connecting them with experts who can further deepen learning. For example, the nonprofit organization, Skype a Scientist, virtually connects classrooms with scientists to foster conversations between students and experts.[44]

In this program, teachers all around the globe can request to connect with scientists working in >25 fields including biomedical engineering, plant pathology, and soil science to schedule conversations between students and professionals tailored to the interests and constrains of each classroom. Similarly, Science Clubs Colombia engages scientists locally and in the diaspora to develop experiential project-based workshops in partnership with local teachers in rural areas of the country including topics ranging from gene editing in bacteria using CRISPR technology, COVID-19 detection and prevention, and muscle tissue engineering.[45] These teaching approaches may be used to discuss biotechnology in further depth while simultaneously encouraging the social and cultural practice of biotechnology.[46]

Higher education

Students in higher education institutions may develop social networks among each other, local communities, and industry partnerships. Within STEM fields, students may develop their social networks through student-led organizations, professional societies, and extracurricular activities (e.g., sports). For example, the Weill Cornell Biotech Club[47] bridges students with industry partnerships and Project Biotech at Shoreline Community College connects college students with high school students for summer camps on biotechnology education.[48,49] Traditionally, STEM students become active members of these social networks by participating in science outreach and pitching ideas to receive funds for industry start-ups, as examples.

As noted in primary and secondary education pedagogical approaches, young scientists are increasingly encouraged to incorporate biotechnology as solutions to complex societal problems. Thus, students pursuing STEM in higher education should also be offered similar pedagogical approaches in social problem solving. One approach, focused on addressing health inequities in society, engages STEM students on health disparities topics in the biomedical engineering curriculum,[50–52] upper-division electives for biology majors,[53] and pharmacy coursework with community-site visits.[54]

In addition to health disparity pedagogical approaches, feminists theory and social justice pedagogy have been used to instruct chemistry students on becoming "precautionary principle chemists" who can codevelop solutions with communities to address sustainability and environmental problems.[55] STEM students may benefit from these approaches by recognizing critical problems facing their social networks and communities

with an added social science perspective. Instructors and higher education professionals should also become aware of these approaches to motivate and guide students in developing novel solutions.

Ideally, by recognizing the social implications of complex societal problems, scientists in all levels of higher education may be further motivated to develop biotechnology with society in mind, which reinforces their innate extrinsic (e.g., fame and money) and intrinsic (e.g., helping society and doing good) motivations for science.[56]

Public Engagement with Biotechnology

Social media

Over the past 15 years, social media platforms have become powerful tools for the dissemination of scientific information. Adults in the United States now cite the internet as their primary source of scientific information.[57] Likewise, global social media use has risen to 4.6 billion active users representing 58% of the world's population.[58] The interactive and responsive nature of these platforms have the potential to lower barriers of access to scientific knowledge. Unfortunately, social media has also facilitated the spread of misinformation related to biotechnology, including in applications such as GM crops and COVID-19 mRNA vaccines.[59,60]

A higher online presence of biotechnology stakeholders in these arenas before and after technologies hit the market could be crucial to combat misconceptions and increase adoption rates. For example, scientists such as Dr. Samantha Yammine (@science.sam), Dr. Bertha Hidalgo (@dr.berthahidalgo), Jessica Malaty Rivera (@jessicamalatyrivera), Dr. Ana Maria Porras (author of this piece, @anamaporras and @anaerobias), and Laurel Bristow (@laurel_bristow) used Instagram throughout the pandemic to engage with nonscientific audiences with the goal of reducing vaccine hesitancy.

Social media allows for the types of personal interactions that can impact public perception of science and scientists. The #ScientistsWhoSelfie study highlighted the power of social media to increase public trust in scientists—particularly women—without affecting perceptions of competence.[61]

These types of strategies do not need to be limited to individuals, organizations can also create strategies to interact with specific communities. The Black Bass Conservation Committee runs its "What's That Bass Wednesday" Facebook posts to challenge its followers (mostly, anglers) to identify fish specimens using photographs while highlighting conservation challenges.[62] Major biotech companies have also started to recognize the impact of social media to raise awareness and support for their technology.[63] The Boehringer Ingelheim communications team runs tweet chats around specific topics (e.g., #COPDchat) that allow patients, doctors, and scientists alike to interact in the same forum.[64]

Likewise, Novartis features patient views and scientist explainer on their social media accounts covering the science of the rare diseases they treat, the clinical trial process, and financial results.[64] Nonetheless, the lack of messaging geared to local (rather than global) populations is a key failure in current digital communication strategies within large biotechnology companies.[65]

To that end, the design of inclusive social media strategies that engage diverse communities is crucial. The dominance of the English language in science poses an important barrier for the participation of most of the world's populations in STEM.[66] Thus, selecting the appropriate language for the intended audience should be a major consideration. These strategies should be paired with culturally responsive communication approaches. The #SaludTues tweetchat campaign by Salud America! for example used bilingual content specifically geared toward Latinx communities in the United States cohosted with experts, advocates, and community representatives to raise awareness on Latinx health equity issues and campaigns.[67]

Owing to the low barriers of access to social media platforms, individuals who identify with groups historically excluded in biotechnology also have opportunities to connect directly with one another and with their respective communities outside of science.[68] Finally, it is important to build accessibility practices[69] (e.g., captions, alt image, and video descriptions) into social media approaches to ensure participation is not limited to able-bodied individuals.

Informal education

Informal education takes place outside the traditional classroom setting and includes museums, community events, festivals, after school programs, and more.[70] These programs allow scientists to connect with multiple audiences and age groups. A wide variety of approaches can provide environments for meaningful interactions with children, youth, and adults in these settings. For example, BioBuilder (founded at MIT) has created free curricula with hand-on activities to explore synthetic biology in formal or informal education settings.[71] The World Biotech Tour, organized by the Association of Science-Technology Centers and Biogen Foundation, brought biotechnology festivals and activities to 12 international science centers and communities from 2015 to 2017.[72]

These types of events provide opportunities for short engagements between practicing scientists and different audiences that impact the participant's perception on science and learning.[73] Nonetheless, these types of engagements should not be limited to academic or nonprofit organizations. Private entities can also build relationships with stakeholder communities. The Corteva Grows Science Outreach Program (formerly Dow AgroSciences Science Ambassadors) provides direct interactions through hands-on activities and answering questions between individuals working in science and the general public in the United States and abroad.[74] Activities take place in a variety of settings from classroom visits to community days to museums with the objective to engage people and allow them to experience discovery.

Regardless of the organizers, a key challenge to these initiatives is their evaluation process.[75] Resources to collect data at events are limited and often are not a priority or area of expertise for scientists engaging in the event. In addition, there are specific protocols around collecting data from youth. A more

thorough compilation of resources and ideas can be found at the Center for the Advancement of Informal Science Education.[70] Creating relationships with organizations involved in informal education allows scientists access and a platform to engage in public discussions, provide answers to questions, and debunk misconceptions.

Citizen Science and Community Participatory Research

Communities can also become more involved with biotechnology as stakeholders in research projects. Citizen science and community-based participatory research (CBPR) are two complementary approaches to engage communities with developing and understanding biotechnology. Citizen science refers to the participation of members of the public in scientific research, which may involve data collection or analysis.[76] Within the realm of biotechnology, multiple research groups have turned to online science discovery games to accelerate the discovery of biological structures.[77] For example, the Eterna project challenges players to develop stable mRNA vaccines and CRISPR guides.[78]

Nonetheless, a variety of factors including access to technology, participation, and language requirements, and data interpretation may turn into bottlenecks that limit the participation of specific populations in these types of projects.[79] Therefore, the intentional design of citizen science activities is paramount to engage the intended communities. CBPR aims to actively involve community members in all aspects of the research process, including providing their expertise in the initial research design phase and carrying out research studies.[80] A few characteristics of this approach include building on the strengths and resources of the community, promoting colearning among research partners, and employing an iterative process to maintain community partnerships.[81]

A common application of biotechnology in CBPR is through the use of molecular diagnostic platforms including studies on HIV screening in African American church attendees[82] and cervical cancer screening among underserved communities in the island nation of Federated States of Micronesia.[83] The two approaches offer opportunities for community members to work closely with scientists and research organizations on biotechnology innovations and implementation.

Policy Making

Public concerns about biotechnology reflect risk perceptions and distrust in regulatory agencies' capacity and competence to address potential threats to public welfare.[84,85] Nonetheless, excessive oversight of biotechnologies can increase the public's vulnerability to biotechnologies that pose a great threat to public welfare if regulatory resources are improperly expended on governing low risk biotechnologies. It can also stifle the pace of innovation by encouraging biotech developers to create imitation biotechnologies to avoid significant upfront product development and marketing costs, and delay the commercialization of novel biotechnologies if biotech developers must prove their biotechnologies are optimally safe through a prolonged and costly regulatory review process.[84]

Risk assessment and management policies that align with the public's values and provide opportunities for public input can alleviate these concerns.[86,87] Regulatory agencies can develop consumer education and outreach policies that communicate the social, economic, environmental, and human health risks and benefits of biotechnologies and how these risks are assessed and mitigated in a manner that is comprehensible and relatable to the public. This builds public trust in the governance of biotechnologies.[88,89] For instance, regulatory agencies can use different communication methods (e.g., internet, radio, television, newspapers, brochures, postcards, magazines, journals, and conferences) to effectively convey policy information that is accessible and culturally and linguistically appropriate to the public.

To resonate with the public, these policies can be written in plain language (i.e., common words and phrases, and avoid scientific or technical jargon and complex or long sentences) with infographics that clearly show why these policies are important to the public, how these policies address the public's needs and align with the public's values and priorities, and what actions the public can take to safeguard their health and the environments where they live, learn, work, and participate in extracurricular activities once they are aware of these policies.[89–93] Similar policies can be created for agencies that fund biotechnology research and development (R&D). These policies can require public transparency on how funded biotechnologies will impact society and address research-to-practice gaps, and the effectiveness and societal implications of accountability measures for grantees.

For example, the National Institutes of Health's Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) programs fund biotechnology R&D for their potential to improve clinical practice. According to the Small Business Act (15 U.S. Code §638), these programs are mandated to inform the public about suboptimal program operations and recommendations for improvement that can impact human well-being and the economy.[94,95]

Policies created to involve the public in decision-making processes regarding biotechnologies are another alternative to addressing the public's apprehension of biotechnology impacts. Regulatory agencies are required by law to inform the public about risk-assessment policies for biotechnologies and allow public comment on those policies to consider the comments in policy reform.[96–98] For example, the U.S. Food and Drug Administration (FDA) hosts public meetings to obtain consumer perspectives on biotechnologies and uses the information to develop policies that set patient-reported outcome metrics to assess how biotechnologies affect the public's quality of life and performance benchmarks for biotechnologies.[99]

However, public comment on new policies for biotechnologies being considered by a regulatory agency does not always influence that agency's actions on those policies. Regulatory agencies base their actions for upholding, modifying, or terminating a new policy on several factors, including public comments, scientific, technical, and economic data, expert opinions, laws, and facts. Public comments are more likely to

influence policy reform when they provide clear, concise, and compelling information relevant to analyzing the proposed policy and its implications.

They should provide content that (1) states whether the public supports or disagrees with the new policy; (2) supports the public's objectives for commenting, while noting any distinctive credentials or lived experiences that explain the public's interest in the proposed policy; (3) provides subject headings to reiterate main points; (4) describes legal or factual issues with the policy while quoting or citing laws and scientific, technical, economic, or other facts overlooked; (5) critiques how the policy was designed, including the involved parties, and its cost effectiveness and potential to disproportionately impact an individual or group of people; (6) includes examples to highlight concerns with the policy; and (7) offers alternative solutions to problems the policy intends to address with evidence, including existing agency policies that have contributed to the problem.

Furthermore, the public can increase the likelihood that their comments will be addressed if they mobilize support for their position among community organizations, lobby the regulatory agency, garner support from a legislator, or obtain press coverage on their position.[100–102]

Policies can also promote the use of implementation science methods during biotechnology R&D. These methods use stakeholder input to identify barriers and facilitators to the uptake of biotechnologies in real-world settings, including safety aspects, and test strategies to mitigate those barriers.[103–105] Policies can as well establish community engagement advisory boards (CEABs) to provide the public with shared decision making, open communication, and transparency about the benefits and risks of introducing biotechnologies into their communities.

CEABs are composed of members from the public and STEM communities that have diverse expertise and lived experiences (e.g., lay members and advocates, leaders of community organizations, research staff, biotechnologists, and engineers). Public members can provide recommendations on the design and implementation of the R&D and commercialization strategy for biotechnologies.

Insights may address how to identify potential community partners; research questions and methods; interpretation of research findings; whether dissemination of research findings is culturally and linguistically sensitive; whether product design processes are informed by user experience, recruitment, and retention plans for clinical trials; implementation approaches; public engagement strategies to reach target communities; and biosafety and environmental issues of concern to citizens.[106,107]

Policy development at different levels of influence can facilitate the adoption and uptake of biotechnology innovations in communities. It can empower the public to actively engage in ongoing dialogue with biotech stakeholders and share in decision-making processes through public–private partnerships that support the formation of community-based advisory boards for biotech R&D and implementation science processes. It can also provide mechanisms for the public to gain a better understanding of how perceived benefits outweigh perceived challenges from integrating biotechnology innovations in their communities. Furthermore, policies made for agencies that provide social, human, and physical capital to support biotech R&D efforts can foster transparency and accountability of biotechnology innovations that are in the best interests of the public and their communities.

Conclusions

Biotechnology offers vast benefits to the environment, animals, and human health, and contributes to improving socioeconomic conditions for the public. However, biotechnology innovations continue to trigger public concern and opposition over their potential social, health, and ecological risks. In general, citizens are risk averse in biotechnology adoption. Thus, initiatives that seek to engage communities in design, development, and adoption processes are crucial for the successful implementation of biotechnology-based solutions. Ideally, these initiatives should arise from all types of sectors (e.g., academic institutions, nonprofit organizations, government agencies, health care, and agricultural industrial organizations) and build relationships with community partners.

Here, we have described a variety of approaches that biotechnologists can use to engage with the public beyond simply communicating information. This access, interaction, and discussion encourages critical thinking, addresses local needs, provides inclusive solutions, and develops trusting relationships with the communities our biotechnology seeks to serve.

Authors' Contributions

All authors contributed to the conception, design, and writing of the article. A.M.P. led the editing and submission process.

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