ACS Synthetic Biology

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Viewpoint

Guiding Ethical Principles in Engineering Biology Research

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Cite This: *ACS Synth. Biol.* 2021, 10, 907−910

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ABSTRACT: Engineering biology is being applied toward solving or mitigating some of the greatest challenges facing society. As with many other rapidly advancing technologies, the development of these powerful tools must be considered in the context of ethical uses for personal, societal, and/or environmental advancement. Researchers have a responsibility to consider the diverse outcomes that may result from the knowledge and innovation they contribute to the field. Together, we developed a Statement of Ethics in Engineering Biology Research to guide researchers as they incorporate the consideration of long-term ethical implications of their work into every phase of the research lifecycle. Herein, we present and contextualize this Statement of Ethics and its six guiding principles. Our goal is to facilitate ongoing reflection and collaboration among technical researchers, social scientists, policy makers, and other stakeholders to support best outcomes in engineering biology innovation and development.

Engineering biology is a rapidly advancing field that uses tools from biology, chemistry, computer science, and engineering to design and build new or modified biological entities such as enzymes, genetic networks, cells, and organisms. Progress in the field is leading to rapid advances in health and medicine, food and agriculture, environmental sustainability, and bioindustrial manufacturing. However, the diversity of engineering biology tools and applications and their pace of development can give rise to ethical and social concerns. While some domestic policies and international treaties govern legal and ethical uses of biotechnology (e.g., ref 1), government policies alone cannot and should not be the only guide to address the ethical decisions researchers can, do, and will face as engineering biology and its applications continue to develop. The field of engineering biology can leverage the expertise of its diverse members, including technical research scientists, social scientists, ethicists, and other humanists, to support a climate that incorporates consideration and consensus-building around ethical issues. The development and articulation of ethical principles can serve to guide and frame discussions within the field as its members seek to increase knowledge and achieve public goods.

We, as members of the Engineering Biology Research Consortium (EBRC), issue this Statement of Ethics in Engineering Biology Research in service of this need (see inset). We intend for it to serve as a guide for researchers as they assess and consider research directions and applications now and in the future. We hope that the international engineering biology research community will consider these principles and values to be appropriate and meaningful standards to which engineering biology research should adhere.

The EBRC is a nonprofit, public−private partnership dedicated to bringing together an inclusive engineering biology community capable of safely and ethically addressing national and global needs. This community includes experts in research, bioethics, security, education, safety, and policy from academia, industry, and government. We study, discuss, and shape the wide scope of possible uses and outcomes of engineering biology. We convene area experts to roadmap goals and directions of the field and consider the amplifying effects of synergistic technologies[2]. Together, using a collaborative and iterative process, we produced this statement.

In the development and publication of this statement, we considered the precedent set by other research communities that have undertaken self-examination during times of technological advancement. For example, in 1975, the conveners of the Asilomar Conference on Recombinant DNA evaluated emerging risks and potential regulations for the use of recombinant DNA[3]. In 2015, researchers convened in Napa, California to consider the scientific, medical, legal, and ethical implications of genome editing technologies and their applications[4], and in 2017, a community of researchers involved in gene drive research published ethical guiding principles for their field[5]. Our statement upholds this type of internal examination within a field and expresses a commit-

Received: March 29, 2021
Published: May 12, 2021

ment to sharing responsibility and accountability for engagement across diverse stakeholders.

EBRC Statement of Ethics in Engineering Biology Research

Engineering biology draws on advances in biology, chemistry, computer science, and engineering to understand, design, and construct biological systems and organisms. As with other science and engineering disciplines, engineering biology can impact society in powerful ways; therefore, the ethical, environmental, social, political, security, and safety-related issues arising from associated technologies require thoughtful and ongoing consideration. The Engineering Biology Research Consortium (EBRC) asserts that understanding such issues is a necessary part of research and must be considered from the outset of any project design, continuing through deployment and management of new technologies and/or products.

The EBRC further asserts that practitioners of engineering biology shall i) seek to create products or processes that benefit people, society, or the environment; ii) consider and weigh the benefits of research against potential harms; iii) incorporate equity and justice in the selection and implementation of engineering biology education, research, development, policy, and commercialization; iv) seek to openly distribute the results of early-stage research and development; v) protect the rights of individuals associated with engineering biology, including the freedom of inquiry of researchers and the free and informed consent of research participants; and vi) support open communication between engineering biology researchers and the stakeholders who might be affected by research, development, and the deployment of new technologies.

Scientists and engineers in the engineering biology community must conduct research in a manner that is consistent with these principles in order to remain in good-standing in the community. They must also be cognizant of and communicate possible negative consequences and misuses of engineering biology research. Appropriate safeguards, informed by safety and security best practices, shall be implemented to prevent undesirable outcomes such as the development of biological or chemical weapons, environmental damage resulting from the inadvertent release of certain engineered organisms into the environment, and the use of engineering biology to perpetuate social inequalities.

The EBRC resolves to bring these principles and issues to the awareness of our community along with governmental and non-governmental organizations in the United States and around the world. We support bioethics education and training for researchers and encourage collaboration among scientists, humanists, and engineers to proactively address equity, justice, and environmental risks and benefits. We will advance the principles described here through transparent, democratic self-governance, support for appropriate public and State oversight and review, and the development, publication, and adoption of research best practices.

THE SIX PRINCIPLES OF THE EBRC STATEMENT OF ETHICS IN ENGINEERING BIOLOGY RESEARCH

The EBRC Statement of Ethics in Engineering Biology Research asserts six core principles:

I. seek to create products or processes that benefit people, society, or the environment;
II. consider and weigh the benefits of research against potential harms;
III. incorporate equity and justice in the selection and implementation of engineering biology education, research, development, policy, and commercialization;
IV. seek to openly distribute the results of early stage research and development;
V. protect the rights of individuals associated with engineering biology, including the freedom of inquiry of researchers and the free and informed consent of research participants; and
VI. support open communication between engineering biology researchers and the stakeholders who might be affected by research, development, and the deployment of new technologies.

These principles outline the responsibilities of engineering biology researchers and those associated with their work. The norms of the field should support maximal intellectual freedom in the exploration of scientific hypotheses. Simultaneously, the field should embrace a cultural standard of careful scrutiny of the potential consequences and impacts of research on people and the planet. The engineering biology community should support a climate in which the ethical concerns of stakeholders within and outside the field are heard, discussed, and can be acted upon. To build this climate, the field can prioritize talks and discussion of these issues at conferences, in journals, in workshops, and through organizational working groups and should engage with those outside the field through two-way communication that may involve ongoing, open dialogue, consultation, and community forums or meetings. The principles in the EBRC Statement of Ethics can be used to guide these activities.

The first principle contends that engineering biology products or processes should seek to provide some public or environmental benefit. Basic research often does not translate linearly to products or processes with benefits to humans or the environment; however this work generates knowledge and understanding, which are valuable of themselves, and contributes to the field's capacity to develop beneficial products and processes in the future.

Technical research advances have the potential to unintentionally cause harm or create the capacity to cause harm to people or the environment. The second principle asserts that researchers should be cognizant of this. They should weigh the benefits of research projects and their applications against potential harms. In so doing, researchers have a responsibility to (i) consider published standards relevant to their fields, such as those set at the Napa meeting on genome editing[4], (ii) work within established legal guidelines and regulations, and (iii) maintain relationships with relevant experts in bioethics and other disciplines who can inform ongoing assessment and decision-making. Such practices will help researchers make informed, holistic decisions about research and development directions that can achieve desired ends while safeguarding against potential harms.

The third principle requires that researchers consider the future uses, applications, and adaptations of their innovations, as well as the populations that may or may not benefit from them. Researchers may come to understand, foresee, and consider the implications of ongoing research and development through consultation with targeted populations, NGOs, medical professionals, governments, and social and behavioral scientists. Through taking such steps, researchers may identify opportunities to optimize research for the development of

https://doi.org/10.1021/acssynbio.1c00129
ACS Synth. Biol. 2021, 10, 907−910

products that are accessible to diverse communities and populations.

The fourth principle supports the distribution of research results. The distribution of basic research and development moves collective knowledge and tools forward, accelerating advancement. While currently well communicated by academics, industrial researchers are encouraged to share more discoveries pertaining to general knowledge.

The fifth principle upholds the rights of individuals associated with engineering biology research. It asserts that investigators operating within legal and ethical bounds should have the intellectual freedom to pursue diverse lines of inquiry and research. It also upholds the rights of human subjects involved in engineering biology research. Where legal requirements do not enshrine and uphold participant entitlement to accurate, timely, and detailed information, researchers have a responsibility to maintain a higher ethical standard. They are encouraged to engage with regulatory officials to codify such standards. Free and informed consent must be affirmatively given in the absence of any form of coercion.

The final guiding principle recognizes that some applications of engineering biology, such as human germline editing or gene drives, may affect entire human populations and/or ecosystems. Various models have been proposed by academics and practitioners to address the rights and roles of populations who may be affected by such applications, ranging from community consultation to "free, prior, and informed consent" to "responsive science"[6−8]. At a minimum, populations have a right to accurate and timely information about engineering biology research applications that may affect them or the environments where they live and should not be prevented from articulating their questions, comments, and/or concerns. Two-way communication and even collaboration between researchers and communities can be beneficial for all involved. Community members benefit from understanding or participating in proposed research and having opportunities to communicate directly with researchers. Listening to communities enables researchers to understand the needs and values of a population and provides opportunities to design and direct research that comports with those values. Partnerships between researchers, social scientists, and community leaders can be useful in identifying suitable modes of engagement given the nature of a research project, researchers, and communities involved.

■ MOVING FORWARD

With this Statement of Ethics, we provide a set of commitments that can be built upon as the field of engineering biology moves forward. Because the field is multifaceted and growing quickly, it is impossible to accurately predict all future challenges and opportunities that both practitioners and policymakers will face. U.S. legislators are working on a bipartisan basis to support engineering biology research and development, biomanufacturing, and workforce development.

The Executive Branch undertook serious consideration of ethics in engineering biology in 2010, following the announcement that scientists at the J. Craig Venter Institute had created the first self-replicating synthetic bacterial cell. President Obama directed the Presidential Commission for the Study of Bioethical Issues to study the implications of synthetic biology. The commission's ensuing report, *New Directions: The Ethics of Synthetic Biology and Emerging Technologies*, encouraged "prudent vigilance" by the government, calling for the regular assessment of potential risks and benefits of research[9]. Prudent vigilance requires the participation of engineering biology researchers and social scientists in governance who can communicate research directions and their potential implications to policymakers. As a result, government officials can maintain awareness of progress and development in the field without imposing undo regulation.

In the 11 years since the report, engineering biology has developed significantly, and now, more than ever, communication and collaboration between researchers, regulatory bodies, and social scientists is needed to support outcomes that safely and ethically support the public good. We hope that the issuance of this Statement of Ethics will guide and buttress these efforts as a supplement to policy and regulation not just within the United States, but for our international community.

We invite our colleagues in the broader engineering biology field to consider, endorse, and practice the principles in this Statement of Ethics. Doing so will serve to move a unified field forward toward greater knowledge, understanding, technical capabilities, and achievement of goals with public benefit. We encourage members of the field to pursue communication, consultation, and collaboration between researchers, bioethicists, social scientists, safety and security experts, regulatory officials, and the general public to maximize critical analysis of research. The EBRC supports and facilitates an engineering biology community that is inclusive of diverse perspectives and values interdisciplinary relationships. As an organization, we are committed to realizing the opportunities to improve life and health on this planet uniquely enabled by engineering biology. We believe that it is important to articulate the principles and values that will guide the field of engineering biology toward making the greatest positive contributions to human and environmental health and well-being.

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https://doi.org/10.1021/acssynbio.1c00129
ACS Synth. Biol. 2021, 10, 907−910

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Funding

R.M., J.L.F., E.R.A., and D.C.F. were supported by the Department of Homeland Security under Award No. 19STFRG00011-01-00. E.R.A. and D.C.F. were supported by the National Science Foundation (NSF) under Award No. 1818248. K.R.B. was supported by the Office of Naval Research N00014-18-1-2611, NSF MCB-1553317, Rice University Nettie S. Autrey Fellowship (2020−2021). A.D.E. was supported by The Welch Foundation F-1654. F.J.I. was supported by NSF awards MCB-1714860, EF-1935120, and IOS-1923321. V.N. was supported by NSF awards MCB-1613677 and MCB-2017932. The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Department of Homeland Security.

Notes

The authors declare no competing financial interest.

■ ACKNOWLEDGMENTS

The authors gratefully acknowledge the contribution of the many members of the Engineering Biology Research Consortium who provided direction and feedback.

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