EBRC Student & Postdoc Association

Biosecurity & Bioethics Education Resource

Lessons plans for engagement and critical thinking

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Executive Summary

Biosecurity and bioethics training can support the life sciences research community in securing and safeguarding biotechnology as it delivers powerful new tools, technologies, and products. However, these topics are currently not well integrated into researcher training. Herein, we provide tools to support trainee exposure to biosecurity and bioethics concepts and suggestions for using them.

We begin by describing approaches to incorporating biosecurity and bioethics education into various academic or professional settings. These topics can be integrated into and/or complement established research conduct courses. They can also be crafted into standalone workshops or discussion sections. We present suggestions for pre-work, classroom or workshop timing, and post-work appropriate for students and researchers at various stages of their academic careers.

To support the outlined biosecurity and bioethics implementation strategies, we include a series of fictional case studies that educators and students alike can use to guide discussions on biosecurity and bioethics. These case studies cover a variety of topics and are of different lengths to fit a variety of settings. The case studies and related questions are meant to help stimulate discourse on this topic and are not intended to create experts. All case studies are purely hypothetical; names, locations, pathogens, and descriptions are fictional.

We end with a variety of resources to help further biosecurity and bioethics education, including i) a framework from a National Academies report[1] for analyzing security hazards in life sciences research; ii) a glossary of key terms related to biosecurity; and iii) additional books, reports, and articles about a variety of biosecurity and bioethics topics. Thus, the training strategies herein may serve as a jumping off point for further and deeper inquiry, analysis, and learning.

[1] National Academies of Sciences, Engineering, and Medicine. 2018. *Biodefense in the Age of Synthetic Biology*. Washington, DC: The National Academies Press. https://doi.org/10.17226/24890.

Introduction

The recent emergence and re-emergence of human pathogens such as SARS-CoV-2, Ebola virus, and mpox highlight the personal, societal, and economic burden of disease on global scales. Research on both pathogenic and non-pathogenic diseases provides critical insights into disease mechanisms and supports the development of effective medical countermeasures, including therapeutics and vaccines. This progress is underpinned by remarkable biological research tools. However, the more we understand about pathogens and the more advanced biological tools become, the more susceptible society may be to their misuse.

Our increased capacity to engineer biological components and systems generates a variety of questions regarding the safety and ethics of these technologies. For example, biological tools could be used to reconstruct a virus, enhance the pathogenicity of a microbe, or suppress human genes encoding various disorders—whether genuinely harmful or merely perceived as undesirable. There are also ongoing questions on what groups get to be involved with the design and application of biological systems, particularly those released into the environment or applied to human health. Biological research and technology must therefore be advanced responsibly. Researchers and other stakeholders in engineering biology ecosystems (and related disciplines) must recognize the potential for harm and misuse in their research and be trained to identify biosecurity hazards, assess ethical dilemmas, and respond appropriately.

Advanced life sciences education and training primarily focuses on the use of research tools to learn about the biological world and on the rapid dissemination of advancements. Biosafety education is always required to work in research laboratories in the United States, but some trainees fail to truly engage with this education and instead complete only the minimal level required for compliance. Biosecurity and bioethics[2] education is generally an afterthought, if it is thought of at all. However, if researchers are trained from the start of their careers to understand the security, social, legal, and ethical implications of their work, they will be better positioned to recognize research directions and tools that have the capacity to cause harm or discord, whether through the creation or broadening of biosecurity vulnerabilities and/or through ethical missteps. Students trained in these topics will also bring biosecurity-conscious and ethically informed decision making to academic, industrial, non-profit, and government spaces. These approaches should help to advance innovation and regulation within the engineering biology sector.

To the knowledge of the authors, there are no required biosecurity focused classes for general life sciences students at the undergraduate or graduate levels. Although many programs and institutions do require that students complete courses in responsible research, biosecurity topics are not often discussed. The ethical conversations in these responsible research classes sometimes span a wide range of disciplines; trainees therefore do not always have the opportunity to engage with in-depth bioethics questions.

There are a number of engineering biology-related communities, such as the Engineering Biology Research Consortium (EBRC), the International Genetically Engineered Machine (iGEM), and the Global Open Genetic Engineering Competition (Gogec), that have biosecurity programming for participants, but student participation is primarily on a voluntary basis. A limited number of additional opportunities, such as the Emerging Leaders in Biosecurity Fellowship, hosted by the Johns Hopkins University Center for Health Security, and the Fellowship for Ending Bioweapons Programs, hosted by the Council on Strategic Risks, exist but may be targeted toward individuals building careers in biosecurity and less so to active researchers. To help identify and share the opportunities that do exist, the authors previously developed the EBRC Biosecurity Opportunities Nexus (BISON). There are similar bioethics-focused opportunities, primarily advanced degree programs, and numerous academic and independent bioethics centers like The Hastings Center or Kennedy Institute of Ethics. Each of these opportunities requires initiative on the part of the individual researcher, rather than being incorporated into standard trainee education.

[2] Here, we define biosecurity as the set of technologies and practices designed to prevent the deliberate misuse of biological tools and bioethics as the set of ethical questions that arise alongside biological research. These terms are often defined differently across fields. More complete definitions can be found in Appendix II.

This Biosecurity & Bioethics Education Resource was developed to serve as a resource for students, researchers, and educators seeking to incorporate biosecurity- and bioethics-conscious analysis into their research, courses, and/or career development. We anticipate that, through the implementation of this resource and/or other approaches to biosecurity and bioethics education and training, the research community will be better able to recognize ways in which their innovative, game-changing research could potentially be misused and actions they can take to safeguard and steward these powerful tools and capabilities.

1. Biosecurity & Bioethics Education Venues and Lesson Plans

Biosecurity and bioethics education, training, and consideration ideally should occur continually throughout one's education and career. Different types of engagement with biosecurity and bioethics may be more appropriate at different times and stages. The information provided in this document was designed to be integrable into a variety of educational formats. We provide implementation examples in i) the biology or engineering classroom; ii) a journal club; and iii) a standalone workshop. These examples are not intended to be exhaustive, and we encourage creativity in implementation. Our implementation examples are primarily framed around biosecurity, recognizing that bioethics is deeply linked to these topics and that several bioethics-specific education resources already exist[3]. For more bioethics-specific conversations, we encourage facilitators to alter pre/post-reading suggestions and concluding questions as necessary.

We note that "biosecurity" is defined very differently between (and even within) fields. A facilitator may wish to begin by recognizing these differences and establishing a definition for the discussion. A brief conversation around community guidelines, such as how to approach controversial topics, may also be helpful in setting expectations for the session[4].

After providing the mechanistic framework for the session, facilitators should then pose one or two guiding questions. These can be tailored to the individual event but might include consideration of capabilities enabled by new and emerging biological tools, research directions with biosecurity and/or ethical implications (e.g., mirror life[5]), or technology use cases that should be considered. Whether broad or specific, the number of questions should be kept small to provide a clear focus for the conversation. Facilitators might consider initiating discussion with a "think-pair-share" exercise where participants are given a short time to reflect on the question individually, then pair with another participant to share thoughts before beginning full group discussion. Following initial discussion, sessions should turn to provided case study(s) and associated discussion questions. In all cases, the quality of discussion should be held paramount. If good conversations are happening, do not cut them short to ensure all guiding questions are answered.

[3] Bioethics curriculum resources include, but are not limited to, the NIH Bioethics Curriculum Supplement, the UNESCO Bioethics Core Curriculum, and Amgen's bioethics curriculum resources.

[4] The Center for Research on Learning and Teaching at the University of Michigan provides several useful sets of guidelines for classroom discussions and discussing difficult or high-stakes topics.

[5] Adamala et al., Confronting risks of mirror life. Science 386, 1351-1353(2024). DOI:10.1126/science.ads9158

Example biosecurity and/or bioethics lesson for a single class period:

Pre-work	*Graduate Courses:*
	• Students should read one or more of the following resources:
	  • "The Blessing and Curse of Biotechnology: A Primer on Biosafety and Biosecurity" by Ronit Langer and Shruti Sharma (here)
	  • "Thinking Ethically About Human Biotechnology" by Margaret R. McLean (here)
	  • The National Security Commission on Emerging Biotechnologies' white papers, such as those below:
	  • Risks of AIxBio
	  • Gene Synthesis Security
	  • Biological Data as a Strategic Asset
	
	High School and Undergraduate Courses:
	• Students should read one or more of the following resources:
	  • "Biosecurity in the Age of Synthetic Biology" by Lee Khai Wooi (here)
	  • "Thinking about Ethics" by Kristen Bjork (here)

During Class	*Graduate and Undergraduate Courses:* • Individually read through one of the short case studies provided in Section 2a. (10 min.) • Answer questions posed for the case study either as a full class or in small groups. If done in small groups, require each group to share either their key discussion points or an answer to a specific question with the full class. (30-35 min.) • As a full class, consider this concluding question: what actions or practices can researchers individually, or the research community more broadly, take to incorporate a biosecurity and/or bioethics mindset into life sciences research? (5-10 min.) *High School Courses:* • Read through one of the short case studies provided in Section 2 as a full class. (10 min.) • Before answering any guiding questions, ask students to find connections between the case study and topics they have discussed in class. (10 min.) • Answer two or three questions posed for the case study as a class. (20-25 min.) • Finish with this concluding question: why are biosecurity and/or bioethics important for researchers to think about? (5-10 min.)

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Example biosecurity and/or bioethics lesson for a single class period (continued):

Post-work	*Graduate Courses:* Encourage students to consider the biosecurity and/or bioethical implications of their own research or research they find interesting. For a biosecurity focus, direct students to apply the framework described in *Biodefense in the Age of Synthetic Biology*[6] (see Appendix I) to their own work. This can be given as a short writing assignment or expanded into a presentation to peers in a later class period. To further supplement, students can read "The security mindset" by Schoenmakers, et al. (here). *Undergraduate Courses:* Students should select a biotechnology they are interested in and identify and assess biosecurity-related questions or concerns using the framework described in *Biodefense in the Age of Synthetic Biology* (Appendix I). This can be given as a short writing assignment or expanded into a presentation to peers in a later class period. *High School Courses:* Have students answer the remaining guiding questions for the selected case study. Encourage them to look for peer-reviewed articles or reputable media articles that relate to the questions.

Example biosecurity and/or bioethics discussion in a journal club:

Pre-work	• Participants should read the following:
	  • "The Blessing and Curse of Biotechnology: A Primer on Biosafety and Biosecurity" by Ronit Langer and Shruti Sharma (here)
	  • A selected case study from Section 2.

During Journal Club	• Begin with a discussion of the key assumptions and claims presented in the article by Langer and Sharma. Do you agree with these claims? Why? How does your research or interests intersect with these considerations? (15 min.) • Transition to discussing the case study and associated discussion questions. (30 min.) • Finish by considering the biosecurity and/or bioethical implications of projects being conducted in your research group(s). How should you carry forward what you learned today immediately and in the future? What questions or concerns should you address, and how? (10-15 min.)

[6] National Academies of Sciences, Engineering, and Medicine (n 1) 23.

Example biosecurity and/or bioethics workshop:

Pre-work	• Participants should read one or both of the following resources:
	  ◦ "The Blessing and Curse of Biotechnology: A Primer on Biosafety and Biosecurity" by Ronit Langer and Shruti Sharma (here)
	  ◦ "Thinking Ethically About Human Biotechnology" by Margaret R. McLean (here)
	• Split participants into small groups. Ideally, each small group should have a wide variety of interests and experiences to facilitate more meaningful discussions.
	• Assign a case study to each group from Section 2 to read before the start of the workshop. The long case studies are more suited to this extended discussion format, but short case studies can be used as well.
	  ◦ Ensure there are multiple case studies spread out across different groups.
	  ◦ Each group should have a facilitator to help direct discussion and address any issues.

During Workshop	• Welcome participants and briefly remind the groups about key definitions and concepts related to biosecurity, drawing on information provided in Appendices I and II. (5-10 min.) • Split the workshop into the pre-assigned groups and start by discussing each person's thoughts on the case study as a whole. Had they thought about these issues before? Are there any similar examples they can identify? (10 min.) • Work through the case study discussion questions. (40-50 min.) • Form new groups that consist of individuals from different case studies (or at least different groups), like a jigsaw activity (here). • Reconvene as a whole group and discuss the big picture takeaways from each case study group's discussions. (10-20 min.)
Post-work	• Encourage participants to relate the biosecurity and bioethics discussions to their own work. Additional resources can be provided at this time, such as those in Appendix III.

2. Hypothetical Case Studies

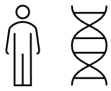
The following fictional case studies describe situations that could arise now or as engineering biology and life sciences research continue to progress. While these cases are purely fictional and drawn from the authors' imagination, we include elements from real world examples of events, groups, and research developments. We hope that these cases can be the basis of robust discussions and help provide context for why biosecurity and bioethics should be integrated into education.

Short Case Studies

Using Artificial Intelligence to Design Pathogens

Releasing Genetically Modified Organisms into the Wild

Editing the Human Genome



Leveraging Traditional Ecological Knowledge

Long Case Studies

Creating an Engineered Viral Pathogen

Access to a Program by a Potential Bad Actor

2.a.1. Using Artificial Intelligence to Design Pathogens

Ariana is a postdoctoral researcher in an infectious disease laboratory focused on understanding the biology, transmission, and treatment of influenza viruses. She seeks to understand how combinations of different hemagglutinin (H) and neuraminidase (N) proteins on the viral capsid affect transmissibility and infection. Ariana received permission and training to work with the known influenzae subtypes commonly implicated in human infection (e.g., H1N1, H3N2, etc.), as well as a set of subtypes rarely seen to infect humans. She has begun to collect a large library of data across the different H and N subtype combinations and hopes to use the data, along with additional information on annual transmission patterns from her collaborators, to train a machine learning model to predict the key subtypes for the annual flu vaccine. Her artificial intelligence-based predictions have so far been successful, and she has even predicted several uncommon influenzae subtypes that could be more harmful than past epidemics should they become prevalent. However, she and her PI are worried about publishing her model and the corresponding data, as they are worried a malicious actor could leverage Ariana's work to design and build a more harmful influenza virus and potentially initiate a dangerous influenza epidemic.

Discussion Questions:

1. Do you think Ariana's research is "dual-use?" What about "gain-of-function"? At what point would it begin to or cease to fit in these categories? See definitions of "dual-use" and "gain-of-function" here, here, and in Appendix II.
2. Is gain-of-function work inherently bad? Why or why not?
3. Computer models can use the same set of data to build models with the goal of increasing or decreasing particular traits of a biotechnology. What responsibilities do researchers and/or academic journals have to make the products of publicly-funded research open-source? Is a model developer at fault if someone uses their model for nefarious purposes?
4. Artificial intelligence and machine learning can be used to enhance and accelerate biotechnology research, but concerns have been raised that AI/ML could enable the misuse of biotechnologies. How might artificial intelligence enable the misuse of biotechnology research? Do the risks outweigh the potential benefits? Why or why not?
5. If you were Ariana and her PI, what would you do?

2.a.2. Releasing Genetically Modified Organisms into the Wild

Dele and Jenna are two graduate students working on an international collaborative team to improve CO_2 sequestration and conversion via genetically modified plants. Their PIs hope to establish small forests of these genetically engineered plants worldwide to reduce greenhouse gases and mitigate the impacts of climate change. Dele recently improved a CO_2 capture pathway in the model plant *Nicotiana benthamiana* (tobacco) and demonstrated its effectiveness compared to the original plant strain. In parallel, Jenna discovered how to transfect *Pinus longaeva* (bristlecone pine) with a gene expressing green fluorescent protein by manipulating *Agrobacterium tumefaciens*, a bacteria that can alter plant DNA. Dele and Jenna plan to combine their two systems to make bristlecone pines that can sequester large amounts of CO_2 for the duration of the tree's long life and slow post-mortem decomposition process. However, Jenna's transfection method is time-consuming and requires recovering the transgenic trees from embryonic callus cultures. One of her modified trees would take over 50 years to reach maturity.

Another PI on the project indicated that her team could explore the development of a novel plant virus capable of inducing transient expression of the CO_2 sequestration pathway. Preliminary work demonstrated that the viral vector would have to be sprayed annually on the tree leaves to maintain activity. The collaborator is confident that using these viruses will not have any unintended environmental impacts. Dele's roommate, an environmental science graduate student, is less sure and has expressed his concerns about the viruses spreading through the water table or creating potentially invasive species. Dele and Jenna aren't sure how to respond to these concerns. They set up a meeting with their advisor to discuss them but are told that the problem of climate change is too significant to worry about "minor, unlikely side effects."

Discussion Questions:

1. Do you think it is a good idea to use genetically modified organisms beyond controlled settings like a laboratory or biochemical plant? What are some of the benefits and risks? Does the method of making transgenic organisms change your answers?
2. Assume that Jenna and Dele's collaborator was able to integrate the CO_2 sequestration pathway in bristlecone pine with the viral vector, at least in a greenhouse setting. She now wants to test her engineered tree outside the greenhouse, in the environment. What factors should she consider when selecting potential testing locations? Are there potential hazards to the ecosystems and people living near them? If so, (how) can these hazards be mitigated?
3. Why are people outside biotechnology-related fields often concerned about "GMOs"? What technical, regulatory, or other safeguards are or should be in place to assuage these concerns? (How) should researchers proceed to test, evaluate, and deploy genetically engineered technologies when public concerns remain after regulatory hurdles have been cleared? (To expand upon and support this discussion, see George et al., 2025[7].)
4. Do you think Jenna, Dele, and their collaborator should continue with their project? Why or why not? Should they make any modifications to their plans?
5. Do you agree with Dele and Jenna's advisor that major problems require us to set aside "smaller" concerns? Why or why not?

[7] George et al. Opening up "containment": Technological and social dimensions of biocontainment for genetically engineered organisms designed for deliberate release. Authorea. April 21, 2025. DOI: 10.22541/au.174526562.21903148/v1

2.a.3. Editing the Human Genome

Dr. Nawaz is an early-career assistant professor at a highly respected teaching hospital and its associated university. Her lab's research focuses on *in vitro* fertilization (IVF) techniques. Dr. Nawaz, her MD/PhD student, and her two resident physician-scientists recently developed a new follicle stimulating hormone cocktail that improves both the quality and quantity of eggs collected from the mother, increasing IVF success rates by roughly 15%. To ensure the health and safety of both the mother and child, Dr. Nawaz maintains strict eligibility parameters for her novel hormone treatment.

Following a recent meeting with her tenure committee, Dr. Nawaz is approached by Dr. Shi, a member of her committee, about a new project he is considering. Dr. Shi explained that he has designed a new protocol to prevent mothers with hereditary hearing loss from passing those genes to their children. However, he sees relatively low survival rates for gametes subjected to this procedure and wants to leverage Dr. Nawaz's techniques to get a better starting pool of eggs. Dr. Nawaz is both surprised and concerned, asking a variety of clarifying questions. After a while, Dr. Shi admits that he is indeed attempting to genetically modify the egg cells to remove genetic mutations and explains that he has gotten IRB approval for his work. Dr. Nawaz is uncomfortable with the project and does not want to participate, but she is concerned saying no will jeopardize her chance at receiving tenure.

Discussion Questions:

1. If you were Dr. Nawaz, what would you do? Why?
2. Under what circumstances, if any, is it acceptable to modify the human genome? Why? Do you draw a distinction between germline editing (altering the egg, sperm, or embryo) versus somatic editing (altering only select cell types, such as blood cells or eye cells, in a patient)?
3. Some deaf community activists view projects like Dr. Shi's work as a form of eugenics. Others believe that if we have the ability to prevent a disability, we have an obligation to do so. What are your thoughts on this debate?
4. Is Dr. Shi's research ethically different from embryonic screening in IVF, which involves identifying and removing embryos with genetic disorders from the implantation pool?
5. In 2018, Dr. He Jiankui used CRISPR to create the world's first publicly acknowledged genetically engineered human babies. You can read more about the story here. Following the reveal of this project, He was largely condemned by the scientific community for a variety of reasons (see here and here) and was later found guilty of engaging in illegal medical practices and jailed by Chinese authorities. In 2023, it was reported that He has returned to developing gene-editing therapies. Do you think any new human gene editing experiments will receive the same response now as in 2018? Should they? Why?

2.a.4. Leveraging Traditional Ecological Knowledge

Jakob works as a staff scientist in a large non-profit research laboratory. Several years ago, he and his colleagues performed a large screen of Amazonian medicinal plants used by Tucano Indigenous communities. One of the identified compounds shows promising antimicrobial activity, and Jakob recently finished designing and validating an enzymatic pathway to produce the complex molecule. The pathway relies on several enzymes found only in the plant that produces the final compound. Jakob is now actively pitching the compound and associated biomanufacturing process to a large pharmaceutical company. Although the company is interested in the novel therapeutic, it is unwilling to abide by the benefit-sharing agreement that Jakob's team established with the collaborating Tucano peoples, whose Traditional Ecological Knowledge pointed Jakob to the compound's original plant source. The company argues that due to the product's small predicted profit margin, they cannot return any percentage of profit to the Tucano communities or biodiversity efforts, nor can they guarantee free access to the therapeutic by the Tucano peoples. Jakob is confident that commercializing the drug will save thousands of lives. He also feels guilty about breaking the benefit-sharing agreement and is unsure how to move forward.

Discussion Questions:

1. Who should get to "own" a naturally derived compound, if anyone? Why?
2. Benefit-sharing agreements between researchers, companies, and Indigenous communities typically consist of both monetary and non-monetary components. These can include profit sharing, royalties, scientific capacity building, and equitable product distribution. Do you think strategies like these are effective in balancing the interests of providers and users of Traditional Ecological Knowledge? Why or why not?
3. How does the end price of a product impact who can access it? Why might this be an ethical concern? Why might this be a concern in biosecurity?
4. How should companies and research organizations balance ethical and economic considerations?
5. If you were Jakob, what would you do?

You can learn more about access and benefits-sharing through resources from the Convention on Biological Diversity (CBD), which adopted the Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from their Utilization (ABS) to the Convention on Biological Diversity *in 2010. Note that the United States is not a signatory of the CBD.*

2.b.1. Creating an Engineered Viral Pathogen

Lucas stormed into the Davis Lab's break room, his face tense with a mixture of anger, confusion, and sadness. The two postdocs sitting at the center table paused their lunch and looked up at the graduate student with concern. During the past month, they had sensed that Lucas was a bit distant and withdrawn, but didn't know what had precipitated today's reaction. The more senior postdoc, Annaclaire, and the new postdoc, Matthew, asked Lucas what was wrong.

The Davis Lab was one of the first labs in the world to acquire samples and begin work on a virus colloquially known as the Delirium Death Virus, or DDV. DDV was an RNA virus originally discovered in 2031 by field scientists from the private company Viral Analysis Corp (VAC). VAC was started by scientists who wanted to use bioprospecting techniques to sample the world's viruses and understand how various viruses behave and evolve. The VAC was founded on the premise that cataloging existing viruses would help to prepare the global community for future outbreaks due to cross-species spillover events.

During a 2031 mission into dense forests within the Republic of Marva, VAC scientists collected a wide variety of samples from forest detritus, unique plant species, and animal specimens trapped with the help of local communities. Many of the scientists had been with the VAC for years, but the trip included several younger staff members still in their probationary period. While handling a blood sample from a wild boar, one of the probationary scientist's hands slipped and he accidentally stuck himself with the contaminated needle. The scientist did not tell his colleagues due to fear of losing his job and continued his work. Four days later, as the group prepared to fly back to Cyta, the country where VAC was based, the scientist began to develop a severe headache. Due to a lack of other symptoms, the scientist assumed he was experiencing travel fatigue and boarded the plane. Within two weeks, hospitals in eight countries, including Cyta, were reporting an influx of patients suffering from debilitating migraines and, in many cases, delirium. A number of these patients who had weakened immune systems also developed meningitis and edema; a majority of them died. Public health officials initiated regional lockdowns to minimize virus transmission and DDV cases plummeted, eventually dropping to zero after two months.

During the DDV outbreak, the Davis Lab began its groundbreaking work on the virus using clinical isolates and testing them on mouse models that near perfectly recapitulated human reactions to DDV. Professor Davis prided himself in characterizing DDV and was pursuing research on DDV therapeutics. Much of this work was funded by VAC.

Over the past few months, a second year graduate student named Mia had been examining a CRISPR-based therapeutic that selectively modified key residues on the primary DDV envelope protein to form stronger bonds with neutralizing antibodies. Mia had previously demonstrated how two separate single amino acid modifications to the envelope protein significantly improved mouse survival after treatment with the therapeutic. However, when she combined the modifications to make a double mutant, Mia was surprised to find that every single mouse in her experimental group died. Worried that she had made a mistake during the experiment, Mia tested the double mutant again with a series of additional controls, including several other therapeutics the Davis Lab had previously shown to reduce death from DDV infection. The results not only were replicated, but showed that the modified DDV, named mDDV_2, was capable of evading the additional therapeutics. In all cases, mDDV_2 led to >70% fatality in previously healthy mice, compared to only 30% with the original DDV.

Concerned by the results, Professor Davis instructed Mia to suspend testing and not share information about the new variant with others until he could speak with their VAC collaborators and university biosafety experts. He said that if others knew about mDDV_2, they might try to use it as a bioweapon or tool of bioterrorism. He also noted that because the project was funded by VAC and not the government, they did not have an initial obligation to report the results to any government authority. Professor Davis emphasized that he wanted to have as much information as possible before going public and potentially causing unnecessary panic.

Mia's mouse cages were close to those used by Lucas. During Mia's mDDV_2 tests, Lucas noticed that mice in his control and test groups were beginning to die more frequently. This confused Lucas; the antibody therapeutic he was developing had previously been highly successful. Lucas asked Mia if she had seen any changes in her survival rates and was met with confusing and guarded responses.

Frustrated by Mia and concerned that his early results had been incorrect, Lucas raised the issue during a one-on-one meeting with their PI. Professor Davis requested his raw experimental data and told Lucas to move his cages and try his experiment again. Lucas, in the fifth year of his Ph.D. program and fairly comfortable with his advisor, continued to voice his concern about Mia's behavior. He was shocked when Professor Davis, who was usually very open with his students, bluntly refused to discuss Mia's work or her hesitancy to answer questions. They ended the meeting on a sour note.

As he returned from lunch later that day, Lucas spotted Mia and Professor Davis engaged in conversation through the frosted glass window alongside their PI's closed office door. This made Lucas even more uncomfortable; Professor Davis only closed his door during important virtual meetings and never during individual meetings with his students.

The next few days further increased Lucas' suspicion. Professor Davis and Mia seemed to vanish from the university building, cancelling their regular meetings without explanation and only showing up briefly to grab packets of papers or files from laboratory computers. Unbeknownst to Lucas, Professor Davis and Mia were in extended discussions with biosafety experts and had nearly finished preparing a package of information with VAC about mDDV_2 for Cyta's Department of Human Health.

The day he stormed into the breakroom, Lucas had sat down at one of the laboratory computers and combed through all of the files associated with Mia's work. He came across unlabeled mouse survival curves showing the dismal survival rates associated with mDDV_2. In horror, he printed off the results and marched into Professor Davis' office, interrupting yet another private meeting with Mia. Lucas angrily accused Professor Davis and Mia of conspiring to make DDV more harmful, rather than trying to cure it. Mia burst into tears. Professor Davis tensely shepherded Lucas out of the room, told him to be patient, and emphasized that he would explain the situation as soon as he could. When Lucas tried to protest, Professor Davis warned him that further investigation on his part would lead to him being disciplined or even removed from the lab.

Annaclaire and Matthew were shocked by the story that Lucas recounted to them. None of them had any reason to distrust Professor Davis or their labmates before, but they now wondered if they should try to uncover more information at the risk of losing their positions. Lucas suggested reporting Professor Davis to the university, and Matthew noted that they might even want to go to the police. As Lucas began to calm down, he grew worried that he was blowing the situation out of proportion. He didn't know what to do.

Discussion Questions:

1. Should Lucas report Professor Davis to the university? To the police? Why or why not?
2. Do you think Professor Davis made the right decision to not tell any of his other students about Mia's accidental discovery? Should he have changed his response to the situation? If so, how?
3. Should Mia have been trying to genetically engineer the DDV envelope protein? Explain your reasoning.
4. What should students do if professors or those with authority are suspected of violating, or are in clear violation of, biosecurity, biosafety, and/or bioethics protocols and standards?
5. Are viral discovery programs such as the one conducted by VAC worth pursuing? Why or why not?
6. The Davis Lab is not the only group working with DDV. Are there any ways that Professor Davis, the VAC, and/or Cyta's government could prevent other groups from developing the same DDV strain without limiting lifesaving research?
7. How and by whom should labs conducting high-risk or high-consequence work be monitored, if at all? Are there any unforeseen implications of monitoring?
8. Are you concerned about insider threats from within the scientific community? Why or why not? How would you approach mitigating this threat?
9. Why is it important for researchers to think about biosecurity? Beyond thinking, what kind of role could or should they play in their labs and at their institutions in fostering, maintaining, or promoting biosecurity best practices?

2.b.2. Access to a Program by a Potential Bad Actor

It's Thursday evening and Professor Ramir is checking the webpage of her research group's new machine learning tool, HEPHA, that was recently made public. HEPHA was the basis for a publication in the journal *Science* and was developed by a combination of graduate students and postdoctoral researchers from her lab. The tool allows users to rapidly design modified proteins with user-defined functions in different bacterial hosts. It also leverages a series of other groups' tools, along with the Ramir Lab's novel metabolic simulations, to provide detailed instructions on how to increase expression of that specific protein in bacteria. In addition to protein design, HEPHA provides protocols, suggests vendors, designs plasmids, and has an automated tool that helps with troubleshooting. The tool features a user-friendly interface and is ideal for those with a moderate to advanced understanding of molecular biology, biochemistry, and synthetic biology. Ramir's students have used HEPHA to rapidly prototype a new pharmaceutical production pathway, increasing access to a complicated therapeutic.

Ramir is one of the youngest research professors at her university to make tenure. Her outstanding research record propelled her through the process, but she prides herself on also being socially conscious. She understands that science and society are inextricably intertwined, and the last thing she would want is her science to be taken out of context or worse, misused. Since developing HEPHA with her research group, she has been aware of its potential biosecurity concerns. Ramir remembers listening to guest lectures on various bioterror threats when she was studying in university, and one part of her shudders to think about what a motivated terrorist would do if they were trained in the sciences and had access to scientific tools. The other, however, sees universities around the globe full of people using the tools of science to solve the world's greatest challenges. In some respects, it would be irresponsible to withhold a tool like HEPHA based on fears of low probability events.

This evening, snow is falling outside and most of her lab has left the building. She's sitting in her office chair, checking the HEPHA webpage, when an email notification appears on her laptop.

UNKNOWN SENDER <michaelbfreearshir241@email.com>
To: <ARamir@university.edu>

Dear Professor Ramir,

Hello. My name is Michael, and I am a scientist from Limaria Technical University. I am excited to use your tool, HEPHA, and had questions. I want to create a new protein that can act on tetrodotoxin and transform it into simple precursor compounds. However, every time I upload my structure files, your webpage tool tells me it cannot process my inputs. I have no issue with adding structures for things like glucose. Adding my preliminary protein sequence, even without the chemical structures, also leads to the webpage crashing and returning "Error Code 1.5.3 – Contact Administrator."

I was also wondering how I can prepare the bacteria for storage and need to source lyophilizers. The web tool said to contact you directly for advice. Please help.

Thank you.
Michael Freearshir

Upon seeing the email, Ramir tenses. Her back muscles tighten and her mind begins to race. Her jaw clenches and unclenches. Although the email seemed innocuous, it contained two red flags. In designing HEPHA, one of her graduate students had recommended adding in indicators that would help them identify potential attempts at misuse of HEPHA. Although not perfect, the indicators were meant to alert Ramir and her group.

The email from Michael contains two indicators that catch Ramir's attention. First, the webpage allows users to upload structure files for desired enzymatic substrates and products in two separate fields. The program was designed to not accept enzymatic products that were on, or closely related to, any toxins on the Biological Select Agents and Toxins List. Second, the webpage crashing and the associated error code was also a programmed response. This was an indication that the user had entered a protein sequence either related to a sequence with a concerning function or predicted to be one through their

machine learning model. Ramir knows that the classification schemes used by their tool could lead to false positives and she wants to believe that Michael was truly hoping to design an enzyme to degrade the neurotoxin. However, recent news updates about Limaria Technical University increase her worry that Michael is actually trying to do the opposite.

Ramir remembers that over the past month, there have been multiple user profiles created on HEPHA originating from Limaria. While this isn't a cause for worry by itself, the users were all traced back to internet protocol addresses in the area of Limaria Technical University with at least one traced to the office of a professor long suspected of being associated with Limaria's putative biological weapons program.

Limaria was a country fraught with internal tensions and social strife, and sadly its effects had seeped into its scientific community. While funding for the biosciences was low compared to other sectors, Limaria maintained a high research budget for pathogens-related work through their Microbiology and Infectious Diseases division, as well as Bioengineering. However, research output, measured by the number of publications, showed the inverse - there were few publications in those fields in the past few years compared to the budget they were receiving. Scientists in the country who recently earned their PhDs in those fields also had surprisingly few publications immediately after graduation compared to their peers in other bioscience fields.

Recent evidence presented to the UN by a trio of Limarian defectors, codenamed the Icebreakers, suggested a variety of activities within a secret bioweapons program. Additionally, Limaria had been on the International List of Concern for six years in a row due to its ties, with 2029 being the only year it failed to make an appearance.

Limaria national science funding (representative fields) for FY 2033

Bioscience Field	**Funding (in Limarats, L)**	**% change from previous year**
Structural biology	0.6	🔽 15%
Biochemistry	1.2	🔽 10%
Cancer biology	0.1	🔽 50%
Microbiology	5.4	🔼 10%
Infectious diseases	8.1	🔼 10%
Immunology	2.6	🔽 25%
Bioengineering	7.1	🔼 10%
Ecology	0.4	🔽 20%
Physiology	1.3	🔽 10%
Marine biology	0.9	🔽 20%

Limaria publications (past 5 years)

Bioscience Field	Publications
Structural biology	89
Biochemistry	134
Cancer biology	7
Microbiology	40
Infectious diseases	35
Immunology	58
Bioengineering	31
Ecology	76
Physiology	94
Marine biology	87

5- year post-PhD publications in Limaria (past 10 years)

Bioscience Field	Publications
Structural biology	18
Biochemistry	21
Cancer biology	2
Microbiology	2
Infectious diseases	5
Immunology	14
Bioengineering	3
Ecology	9
Physiology	21
Marine biology	24

Ramir shuts down her computer, leaves the research building, and walks towards her car at the top floor of the parking garage. Her head bends slightly to one side as she walks. A passerby would assume she is deep in thought, her face hidden behind a large scarf to buffer against the harsh winter wind that bites at her skin. And indeed, Ramir is deep in thought, her mind racing. Are the two alerts pointing towards something nefarious? Ramir doesn't want to cause a witch hunt and demonization of the scientific profession. Distrust of the scientific community is at an all-time high after a number of prominent scientists were found to have duplicated images, fabricated data, and misled grant awarding agencies for over a decade. One case resulted in a patient death after drug toxicities were not properly documented. At the same time, she doesn't want bad actors to get their hands on a biological weapon developed using her own lab's research.

HEPHA is powerful and she knows it. When it was first published, she received numerous calls to address the tool's potential biosecurity concerns. One camp said the threat was overblown. The other said her work was enabling terrorists. Ramir had tried to address as many concerns as possible and be realistic about possible biothreats without removing the tool from public use, but she still feels like she is caught in the middle.

Ramir finally reaches her car. She opens the door to her SUV and quickly enters, closing the heavy door behind her and turning on the ignition. As the car warms up, she looks up Michael's profile on the Limaria Technical University's website. The automatic translation provided by her browser is not perfect, but the listed research interests align with the email she received. However, she notices that although Michael has been with the university for nearly four years, he only has three listed publications on topics unrelated to neurotoxins, and two were from nearly six years ago.

Her drive home is uneventful, but the thought of HEPHA burns steadily. She mulls over all of the ways Michael could have accidentally triggered their biosafety failsafes, and all of the ways he could be trying to circumvent them. The tires of her car crunch over the freshly fallen snow as she pulls into her home garage.

Ramir makes her way inside her home, turning on dim lights that throw shadows around the room but cast a warm glow on her walls. She places a glass of sparkling water on her coffee table and crouches down in front of the fireplace. As she strikes a match and tosses it onto the logs, packed loosely with newspaper, she considers how these same simple steps are used for any fire, regardless of the intent. Ramir stands, grabs her sparkling water, and settles onto her couch to watch the snow continue falling. She ponders how, or if, she will respond to Michael's email in the morning, and whether her concerns are realistic.

Discussion Questions:

1. Do you have any concerns about HEPHA (biosecurity and otherwise)? Why or why not?
2. Do you think Michael has nefarious intentions? Why or why not?
3. What additional indicators or red flags would you need to see before you categorize Michael as a potential bad actor?
4. Do the rumors that Limaria may have a biological weapons program increase, decrease, or have no effect on your judgement of Michael's email and his intentions? Why?
5. If you were Professor Ramir, what would you do next? Would you notify the authorities? Who would you contact? Would you know who to contact?
6. Should there be user-verification and access controls on machine learning-enabled biological science tools, or should these tools be freely accessible by everyone?
7. How should open science be weighed against biological risks and threats?
8. Should a researcher's country of origin or other personal or professional associations subject them to more scrutiny?
9. Assuming you did not notify the authorities, a suspected bioterror event occurred in a country adjacent to Limaria, and the perpetrators were found to have received help from various research scientists at Limaria Technical University - how would you react? Would you contact the authorities now? Would you take HEPHA offline?

Appendix I – Malice Analysis and the *Biodefense in the Age of Synthetic Biology* Framework

Advances in engineering biology have led to innovations that contribute to the health and well-being of society and the planet. However, the tools, methods, and applications they provide could also be misused for nefarious purposes. The Malice Analysis workshop was designed by the EBRC to help researchers better understand the historical background of biological weapons, potential risks their own research poses, methods to mitigate harm, and how to elevate concerns.

As a workshop, the central interactive component of Malice Analysis offers a chance for participants to identify potential security concerns around their own research using a framework developed and published in a 2018 National Academies of Sciences, Engineering, and Medicine (NASEM) report titled *Biodefense in the Age of Synthetic Biology*[8]. Here, we provide the general outline for a Malice Analysis workshop. Figure 2 describes four key factors—*usability of the technology*; *usability as a weapon*; *requirements of actors*; and *potential for mitigation*—from the NASEM Framework for assessing the level of concern warranted by a given technical capability.

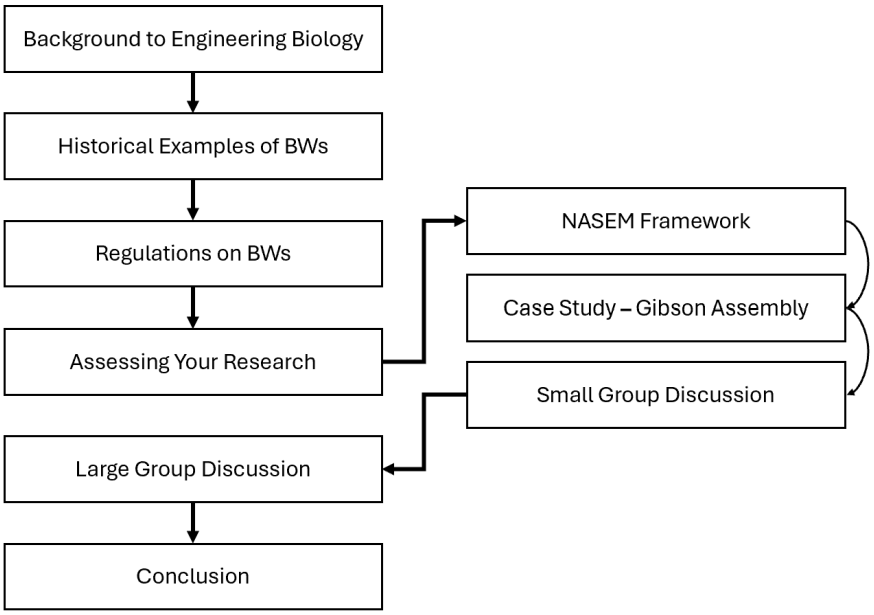


Figure 1. Sample Malice Analysis workshop plan. The workshop typically proceeds as displayed. An introduction to the field is given before the NASEM framework and a case study are presented. Participants then are divided into groups to discuss their research projects before a group discussion and conclusions are given.

[8] National Academies of Sciences, Engineering, and Medicine (n 1) 23.

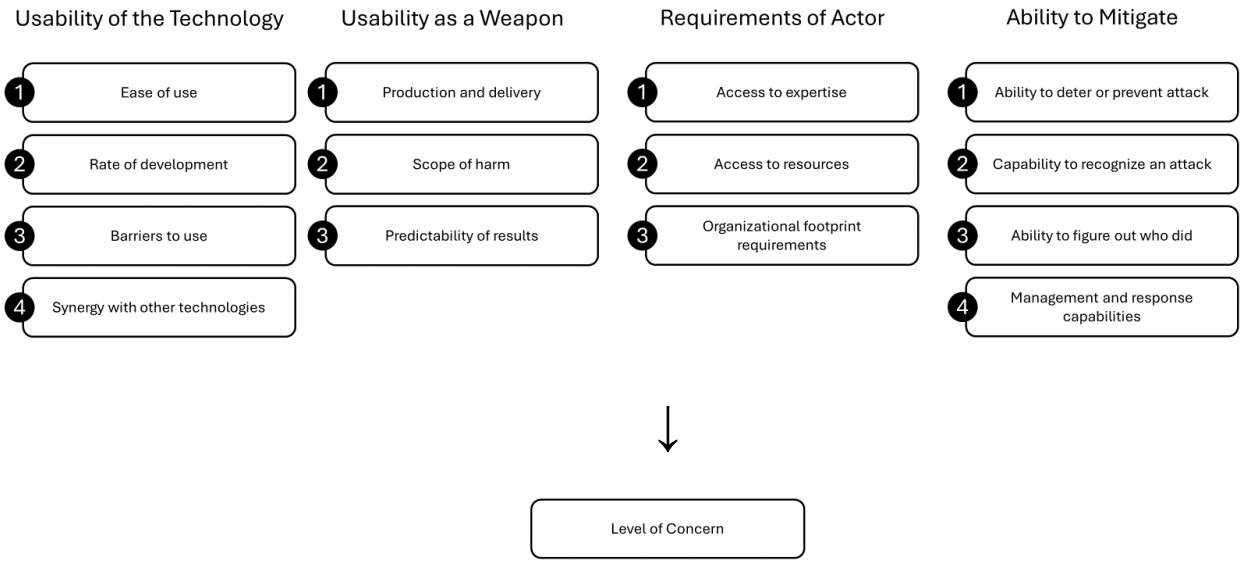


Figure 2. NASEM Framework for assessing research for biosecurity concerns. The framework is divided into four main topics and is one example of how a researcher can think more critically about their own research. The combined analysis of each section can provide a general overview for the level of concern that research may hold.

For more information about Malice Analysis, please follow the following link: https://ebrc.org/malice-analysis/ and contact EBRC if you have any questions.

Appendix II – Key Terms and Definitions

Primary Definitions:

Biosafety: The proper handling procedures and containment principles that prevent the accidental or unintentional release of, spread of, or exposure to biological materials such as pathogens and toxins. This includes the use of personal protective equipment, adequate disposal methods, and safe storage practices.

Biosafety Level (BSL): Laboratory biosafety rankings based on the level of biocontainment precautions necessary to effectively isolate the biological agent(s) being used in the laboratory. The BSL scale ranges from BSL-1 (lowest level of biocontainment; used for non-pathogenic agents) to BSL-4 (highest level of biocontainment; used for severe or fatal agents without vaccines or treatments). There are 51 BSL-4 laboratories in operation worldwide (see globalbiolabs.org for more information).

Biosecurity: Biosecurity is defined differently by different parties. Here, it is defined as the set of actions, practices and technologies that are designed to protect, control, and account for biological agents and related biotechnologies to prevent the deliberate misuse of biological tools, technologies, or materials.

Biodefense: The set of actions that are aimed at preventing, reducing, and responding to biological threats.

Biological Threat: An infectious microorganism, virus, or other agent capable of causing disease. It may or may not be contagious.

Biorisk Management: A discipline at the intersection of biosafety, biosecurity, and biodefense that pertains to the assessment, mitigation, and evaluation of measures to increase biosecurity and reduce biorisk.

Gain-of-Function (GoF) Research: The National Science Advisory Board for Biosecurity (NSABB) defines gain of function as: "changes resulting in the acquisition of new, or an enhancement of existing, biological phenotypes" (from: A Report of the National Science Advisory Board for Biosecurity, May 2016). There is significant debate over the use of this term and what constitutes gain-of-function research, particularly in regards to biosecurity and how regulations should be formulated around the term and associated research. GoF experiments are routinely conducted as part of standard biological research.

Dual-Use: Any technology or product that can be used for both military and civilian purposes. In addition, misuse of dual use technology could pose a threat to human health and wellbeing on different scales. Dual-use biotechnology often refers to potentially harmful biological agents, research methods, or their applications. Note that "Dual-use" is a less precise term than "Dual-Use Research of Concern" (DURC) which, in the United States, has specific associated policies.

Sequences of Concern: Nucleic acid sequences that can contribute to pathogenicity or harm if introduced into new genetic frameworks.

Additional definitions and more detailed discussions of these terms can be found in the World Health Organization's *Global guidance framework for the responsible use of the life sciences* (available here) or the NIST Bioeconomy Lexicon (available here).

Organizations, Institutions, and Conventions:

1925 Geneva Protocol: Also known as the "Protocol for the Prohibition of the Use in War of Asphyxiating, Poisonous or Other Gases, and of Bacteriological Methods of Warfare." Was signed in 1925 and entered into force in 1928.

Australia Group: A group of countries that first met in 1985, and continues to meet, to align export control approaches to prevent the spread of chemical and biological weapons.

Biological Weapons Convention (BWC): A 1975 international agreement between 189 United Nations Parties and States that prohibits the development, production, acquisition, transfer, stockpiling, and use of both biological and toxin weapons. More information can be found here.

BWC Implementation Support Unit (ISU): Part of the United Nations Office for Disarmament Affairs tasked with overseeing the BWC and its activities.

Cartagena Protocol on Biosafety: A supplementary agreement to the Convention on Biological Diversity aimed at protecting biological diversity and human health alongside the rise of genetically modified organisms.

Contract Research Organization (CRO): An organization that conducts a variety of research activities for a fee.

Convention on Biological Diversity: A 1993 convention between 196 States, not including the U.S., that aims to identify strategies to conserve and sustainably use biological diversity. The convention explicitly covers diversity at the ecosystem, species, and genetic levels.

Federal Select Agent Program: U.S. program managed by the Centers for Disease Control and Department of Agriculture. This program maintains a database of select agents that "pose a threat to public, animal, or plant health" and oversees the use of these agents.

Institutional Biosafety Committee: The group of administrators and subject matter experts that review and oversee all proposed research projects that involve potential biohazards, such as the use of recombinant or synthetic DNA, pathogens, transgenic animals, or human materials.

International Gene Synthesis Consortium (IGSC): A group of leading gene synthesis companies and organizations that have agreed to implement screening protocols to identify and remove dangerous gene sequences and potential bad actors posing as legitimate customers. The IGSC represents the majority of gene synthesis output in the world.

ISO 3500: Developed by the international Organization for Standardization. The document outlines how to "identify, assess, control, and monitor the risks associated with hazardous biological materials" (from ISO).

Nagoya Protocol: A supplementary agreement to the Convention on Biological Diversity that seeks to equitably share and use genetic resources and their subsequent products.

UNSC Resolution 1540: In this resolution, "the Security Council decided that all States shall refrain from providing any form of support to non-State actors that attempt to develop, acquire, manufacture, possess, transport, transfer or use nuclear, chemical or biological weapons and their means of delivery, in particular for terrorist purposes. The resolution requires all States to adopt and enforce appropriate laws to this effect as well as other effective measures to prevent the proliferation of these weapons and their means of delivery to non-State actors, in particular for terrorist purposes" (from UNODA, UN Security Council Resolution 1540).

A selection of additional federal legislation and executive orders related to biosecurity in the United States can be found on the Department of Health & Human Services website, as well as the National Agriculture Law Center website.

Techniques and Tools:

Artificial Intelligence (AI): A field and capability that applies computer science approaches towards designing systems that can mimic aspects of human intelligence. AI includes many sub disciplines such as machine learning, deep learning, computer vision, and natural language processing.

Machine Learning (ML): The underpinning of most modern artificial intelligence. ML relies on the use of statistical algorithms to "teach" a computer how to recognize, generalize, and apply a large data set to a given task.

Biodesign Tools (BDTs): Tools that incorporate biological data in AI models such as ML and deep learning. BDTs can include protein design and structure prediction.

CRISPR: A commonly used tool for genetic engineering, also known as genome editing. CRISPR, which stands for Clustered Regularly Interspaced Short Palindromic Repeats, was developed by using proteins that form a bacterial "immune system" in many prokaryotes. More information on CRISPR and its uses can be found here.

Germline Editing: Genetic engineering performed on the human germ cells, which produce eggs and sperm, as well as early stage embryos. Genetic changes made to the germline result in heritable changes that can be passed from parent to offspring.

Reverse Genetics: An approach in biology that utilizes genetic perturbations to understand phenotypic outcomes. The opposite of forward genetics that maps phenotypic changes to genetics.

Appendix III – Select Readings

The resources included below represent a small selection of books, papers, and news articles that provide a look into the world of biosecurity and bioethics. This list is by no means exhaustive; there are plenty of other great resources on this topic.

Books:

Ken Alibek, *Biohazard: The Chilling True Story of the Largest Covert Biological Weapons Program in the World - Told from Inside by the Man Who Ran It* (New York: Delta, 1999)

Sonia Ben Ouagrham-Gormley, *Barriers to Bioweapons: The Challenges of expertise and Organization for Weapons Development* (Ithaca: Cornell University Press, 2014)

I. Glenn Cohen, Nita A. Farahany, Henry T. Greely, & Carmel Shachar, eds. *Consumer Genetic Technologies: Ethical and Legal Considerations* (Cambridge: Cambridge University Press, 2021)

Jeanne Guillemin, *Biological Weapons: From the Invention of State-Sponsored Programs to Contemporary Bioterrorism* (New York: Columbia University Press, 2006)

Robin Wall Kimmerer, *Braiding Sweetgrass: Indigenous Wisdom, Scientific Knowledge, and the Teachings of Plants* (Minneapolis: Milkweed Editions, 2013)

Gregory Koblentz, *Living Weapons: Biological Warfare and International Security* (Ithaca: Cornell University Press, 2009)

Filippa Lentzos, ed., *Biological Threats in the 21st Century: The Politics, People, Science, and Historical Roots* (London: Imperial College Press, 2016)

Judith Miller, Stephen Engelberg, and William Broad, *Germs: Biological Weapons and America's Secret War* (New York: Touchstone, 2001)

Sheila Jasanoff, *The Ethics of Invention: Technology and the Human Future* (New York: W.W. Norton & Company, 2016)

Osagie K. Obasogie & Marcy Darnovsky, eds., *Beyond Bioethics: Toward a New Biopolitic* (Berkeley: University of California Press, 2018)

Richard Preston, *The Hot Zone: The Terrifying True Story of the Origins of the Ebola Virus* (New York: Knopf Doubleday, 1994)

Lijun Shang, Weiwen Zhang, and Malcolm Dando, eds., *Essentials of Biological Security: A Global Perspective* (New Jersey: Wiley, 2024)

Rebecca Skloot, *The Immortal Life of Henrietta Lacks* (New York: Crown, 2010)

Susan Sontag, *Illness as Metaphor and AIDS and Its Metaphors* (New York: Picador, 1977, 1988)

Jonathan B. Tucker, ed., *Innovation, Dual Use, and Security: Managing the Risks of Emerging Biological and Chemical Technologies* (Cambridge: MIT Press, 2012)

Kathleen M. Vogel, *Phantom Menace or Looming Danger? A New Framework for Assessing Bioweapons Threats* (Baltimore: Johns Hopkins Press, 2012)

Alison Young, *Pandora's Gamble: Lab Leaks, Pandemics, and a World at Risk* (New York: Hachette, 2023)

Stuart Ritchie, *Science Fictions: How Fraud, Bias, negligence, and Hype Undermine the Search for Truth* (New York: Metropolitan Books, 2020)

Laurie Zoloth, *May We Make the World? Gene Drives, Malaria, and the Future of Nature* (Boston: MIT Press, 2023)

Papers, Publications, & Other Resources:

U.S. Department of Health & Human Services Biosecurity Resources (here)

Engineering Biology Research Consortium Publications (here)

Bioethics Briefings from The Hastings Center (here)

“Biodefense in the Age of Synthetic Biology” by the National Academies, 2018. (here)

“Case Studies: Thinking Ethically about Cutting Edge Biotechnology” by Madeline Eiken, Markkula Center for Applied Ethics, 2019. (here)

“Global Guidance Framework for Responsible Use of the Life Sciences” by the World Health Organization (here)

Global BioLabs Project (here) and 2023 Global BioLabs Report (here)

“Security Considerations at the Intersection of Engineering Biology and Artificial Intelligence” by the Engineering Biology Research Consortium, 2023. (here)

“Partnerships with Indigenous Peoples for an ethical bioeconomy” by Maria C.T. Astolfi, et al., 2025. (here)

Access and Benefit-Sharing Info Kit by the Convention on Biological Diversity, 2010. (here)

“Can large language models democratize access to dual-use biotechnology?” by Soice, et al., 2023. (here)

“Which COVID studies pose a biohazard? Lack of clarity hampers research.” by Callaway & Kozlov, 2022. (here)

“Synthetic biology: Recent progress, biosafety and biosecurity concerns, and possible solutions.” by Wang & Zhang, 2019. (here)

“Biosafety and biosecurity in Synthetic Biology: A review.” by Gómez-Tatay & Hernández-Andreu, 2019. (here)

“Promoting biosecurity by professionalizing biosecurity.” by Moritz, et al., 2020. (here)

“Science Has a Nasty Photoshopping Problem” by Elisabeth Bik. The New York Times, 10/29/2022. (here)

“Bent Over in Pain: Student Infected with Debilitating Virus in Undisclosed Biolab Accident” by Mara Hvistendahl. The Intercept, 11/01/2022. (here)

“What an Alzheimer’s Controversy Reveals About the Pressures of Academia” by David Robert Grimes. The Atlantic, 07/29/22. (here)