Promoting Biosecurity Awareness and Responsibility by Embedding it in Life Science Undergraduate Curriculum

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Abstract
Continually emerging biotechnologies and advancing techniques are increasing the world's attention to the potential dual use of scientific research, and the possibility of significant risks to global health and security. It is imperative to establish a fundamental understanding in the life science community of the role scientists play in mitigating these risks and protecting national security. However, linking the life sciences and global security has not always been highly prioritized. Past surveys have shown a significant lack of biosecurity education and awareness in the life science community and has subsequently led to multiple plans, including policies, regulations, and awareness raising measures, to address this problem. Utilizing a review of the existing surveys and papers addressing the better integration of science and security, this paper proposes a way to create a true paradigm shift. By providing biosecurity education, as early as possible, to the next generation of scientists, it will be possible to change the way the life science community thinks about its active role in promoting and protecting security. Undergraduate life science course offerings at some of the top universities in the United States were surveyed. The results suggest there is a substantial void of biosecurity education offered to these young, future working scientists. It is vitally important that universities across the United States, and the rest of the world, develop programs and courses to fill this void, to build a foundational knowledge of biosecurity topics in undergraduate life scientists. This early education and awareness is essential to ensure the continued practice of responsible science that will help protect the global health security of the future.

Biosecurity is an Important Issue
Throughout history, one can find multiple occasions that biological and chemical weapons have been used, and provide a basis for understanding how biology has been exploited for nefarious purposes. For example: in the 14th century the Mongols hurled plague-infected cadavers into cities[1]; during the French and Indian war the French gave Native Americans smallpox infected blankets[2]; during WWII the Imperial Japanese Army dropped 'flea bombs' carrying the bubonic plague on the Chinese[3]; in the 1980s the Rajneeshee Cult in Oregon contaminated salad bars with salmonella for political purposes[4]; and in 2001 an army biologist mailed deadly anthrax spores to news agencies and a congressional building[5]. However, because of advancing 21st century technology these events are not wholly indicative of the current potential threats. Modern day science is constantly coming up with new convergent technologies in pursuit of promoting the advancement and betterment of society, but these same novel technologies can create new unknown potential risks to global security.

The importance of these risks are recognized in the 2018 National Biodefense Strategy: "*It is a vital interest of the United States to manage the risk of biological incidents. In today's interconnected world, biological incidents have the potential to cost thousands of American lives, cause significant anxiety, and greatly impact travel and trade.*"[6] A bioincident has the potential to be catastrophic, but at the same time the nature and likelihood of such an incident is largely unknown. Though it is impossible to fully predict and prevent such an incident, states can, and ought to, take proactive measures to mitigate the risks.

The Relationship between Scientific Research and Biosecurity

At the turn of the century biosecurity discussions began to focus heavily on an issue which came to be known as the 'dual-use dilemma'. This issue was brought to the public forefront in 2001 when a group of Australian's scientists were working with genetic engineering techniques in an attempt to induce infertility in mice as a form of pest control. However, they inadvertently developed a strain of Mousepox virus that could kill even vaccinated mice.[7] When they published their findings in public scientific journals, the public was quick to raise concerns. There was fear that the public release of this information could potentially aid terrorists in creating weapons by utilizing similar techniques. As a result, many believed that the research should not have been published.[8] This controversy was not the first of this kind, nor was it the last. The discovery of recombinant DNA in 1972[9], the artificial synthesis of the live polio virus in 2002[10], the complete reconstruction of the 1918 Spanish flu virus in 2005[11], and the complete synthesis of a Horsepox virus in 2018[12], are just a handful of cases that have demonstrated security concerns raised by modern scientific research. The 2018 National Biodefense Strategy proclaims the advancing 21st technologies will only exacerbate these concerns: "*Advances in the life sciences will both reduce the technological hurdles to such weapons and expand the number of individuals with relevant skills to effectuate threats.*"[6]

Arguably, almost all scientific research has certain dual use potential, however that does not mean that all scientific research is a threat to biosecurity. To help establish where scientific research and biosecurity intersect, the National Science Advisory Board for Biosecurity (NSABB) defined a new category they termed Dual Use Research of Concern (DURC) that has been adopted by the U.S government. DURC is defined as: "*…life sciences research that, based on current understanding, can be reasonably anticipated to provide knowledge, information, products, or technologies that could be directly misapplied to pose a significant threat with broad potential consequences to public health, safety, agricultural crops, and other plants, animals, the environment, material, or national security.*"[13]

But this definition has led to the question of how to determine if scientific research is 'of concern' or not? And if it is, what is to be done about it? Though there are many different proposed answers to these questions, almost all involve one commonality, and that is the need for life scientists to become more involved in promoting effective biosecurity measures. Furthermore, scientists need to be aware and properly educated on their role and responsibility to protect global health security.

To address this dual use dilemma, a variety of formal policies that have been suggested would regulate scientific research. Most of these have not been well received amongst the scientific

community. Historically, scientists have instead favored methods of self-governance. This has often proven to be successful, however for biosecurity, complete self-governance is impractical on a large-scale international level. It seems likely that some some formal regulations and policies will be needed. To be ready to adapt to future changes in policies and regulations, the formulation of the regulations need to take into account the nature of the scientific community. Biosecurity education can help establish an environment where scientists can effectively collaborate with the security community in the development of polices and regulations that will promote security, without impeding scientific freedom.

The Call for Biosecurity Education of Life Scientists

A World Health Organization (WHO) project[14], on responsible life science research for global health security states: "*A culture of scientific integrity and excellence, distinguished by openness, honesty, accountability, and responsibility, is the best protection against the possibility of accidents and deliberate misuse, and the best guarantee of scientific progress and development"*, and to achieve this countries and institutions should consider, "*investing in training personnel (laboratory staff and researchers) and students in ethics, the responsible conduct of research, and biosafety and laboratory biosecurity."* Education as a measure to mitigate potential biosecurity threats has been proposed by multiple organizations over the years demonstrating that there is a continued interest in pursuing it as a preventative measure. The topic of education of scientists has been a prominent theme at the conference meetings of the Biological Weapons Convention (BWC) State Parties, been addressed by important agencies including the National Science Advisory Board for Biosecurity and US Federal Bureau of Investigation (FBI), and is the topic of several professional and independent publications.

Building a responsible scientific community with an engrained sense of moral obligation to mitigate biosecurity risks, begins by increasing working scientists' knowledge and awareness of the issues, at the beginning of their scientific careers. In their undergraduate education, scientists are taught fundamental concepts and basic best practices of safety and ethics in scientific research. They should also be taught the fundamentals and basic best practices they, as scientific researchers, should implement to protect national and international biosecurity. To raise awareness of the potential biosecurity implications of their research, their curriculum should include the history of biosecurity, current biosecurity policies, and previous biosecurity incidents involving scientists.

Current Scientific Community Education Practices

Together, good biosafety, bioethics, and biosecurity practices provide a solid foundation for a community of responsible researchers. Biosafety procedures address accidental exposures and releases, bioethics teachings emphasize the importance of honest, valid, and humane research practices, while biosecurity works to prevent intentional misuse of technology and ideas. Biosafety, bioethics, and biosecurity each address separate categories of scientific practices, therefore distinct education and training on the best practices of each is essential for ensuring safe and responsible science. Currently, biosafety and bioethics receive more attention when it comes to mandatory training and education of life scientists, perhaps because the direct correlation between these topics and scientists is more obvious. The role of life scientists in biosecurity could be seen as more abstract.

Biosafety training is often given at multiple stages of a scientist's career, usually starting before work begins in a laboratory setting. The need for laboratory biosafety education and training is obvious, as is illustrated by the vast array of programs enforced throughout the scientific community. Multiple laboratory biosafety requirements for scientists are in place to ensure anyone handling laboratory materials has had the proper training. To supplement these requirements there are multiple online biosafety modules, handbooks, and manuals on safety. Biosafety training is introduced early in a scientist's education, likely incorporated into their introductory science courses, and is then continually built upon as they progress through their education and careers. Though there are biosafety practices that are general and apply to all scientists, biosafety training is also tailored to each scientist's specific needs based on their unique jobs and research. For this reason, advanced biosafety education is often given on more specific, individual levels.

Bioethics training is also widely practiced in the scientific community. Like biosafety, bioethics is generally seen as part of the fundamental education one must receive to be involved in the scientific practice. The scientific community heavily relies on its members to have good moral obligations and to abide by a responsible code of conduct. Like biosafety, bioethics training is often mandatory for life scientists. One example is the National Institute of Health (NIH) *Responsible Conduct of Research (RCR)* training requirement for all personnel working on NIH funded programs. This RCR training and other ethics education modules focus on honesty of research (not faking data), sharing and ownership of data, and proper human and animal subject research conduct. Bioethics education is typically formally introduced early in a scientist's education within general courses, and good practices are constantly reinforced through a scientist's career both by formal training programs and more significantly through informal reinforcement by the community. The scientific community takes pride in pursuing knowledge for the betterment of society in an honest, responsible manner.

Biosecurity training is very different than standard biosafety and bioethics practices. Though there are some current online modules and resources for biosecurity training such as the new 'Bioagents Education App' available on IPhones, there is no universal understanding of the need for mandatory biosecurity education of life scientists comparable to that of biosafety and ethical research practices. Online programs, seminars, and workshops focusing on biosecurity have been developed in the U.S., Europe, Japan, and others, however, currently, they only reach a limited audience. One notable outreach program is how the FBI works with the iGEM competition where more than 6,000 people, mainly university students, from multiple countries compete each year in pushing the boundaries of synthetic biology.[15] The FBI, working with other national organizations, has partnered with iGEM to ensure the students in this competition are educated on the security concerns and implications their work could have. The FBI also partners with the American Association for the Advancement of Science (AAAS) to organize other workshops, conferences, and meetings between leaders in security and science to attempt to bring the two communities together and encourage collaboration.[16] Though these programs, along with others, have been successful in increasing awareness and education of security issues amongst the scientists they reach, there needs to be a way for this information to be more prominently disseminated in order for a true paradigm shift to occur in the scientific community. Undergraduate education could most certainly serve as the proper platform for this.

Biosecurity Education Opportunities at Universities

Several surveys have been conducted to determine how much, if any, biosecurity education is offered at the university level. In 2008 the University of Bradford in the UK published the results of a survey of 142 undergraduate and masters level life science degree courses from 57 universities in 29 countries in Europe that looked for evidence of biosecurity modules and compared them to the amount of bioethics and biosafety modules. Their findings indicated only 3 out of the 57 Universities offered a form of a biosecurity specific module, and if it was offered it was optional.[17] Their findings also showed that there was a considerable amount of bioethics modules, and about one fifth of life science degrees in the sample had a specific biosafety module. A similar survey was then conducted in Japan, which produced very similar results. Out of 197 life science degree courses in 62 universities, only 3 biosecurity specific modules were found.[17] Also in 2008, the AAAS conducted a survey in the United States to identify course areas intended to specifically educate scientists about dual use life sciences research. The survey included colleges of medicine, veterinary medicine, nursing, public health, engineering, and sixty top research institutions. The survey identified four separate categories of education courses that addressed the dual use research: biodefense policy courses, biosafety training programs, bioterrorism preparedness courses for public health students, and biosecurity education programs for scientists. Only fourteen biosecurity education courses for scientists were found and were primarily for graduate students in the life sciences.[18] Collectively, these surveys illustrate that while there was a decent amount of bioethics and biosafety education, there was a substantial lack of biosecurity specific education at universities across the world in 2008.

To provide a glimpse of current biosecurity education, specifically at the undergraduate level, a brief internet survey was conducted. The search was limited to courses offered through life science departments (while including bioengineering and biochemistry). The review of course catalogs from eight top public and private U.S. universities, found that only two of these universities offered specific biosecurity courses to undergraduate students: at UCLA through the department of Epidemiology and at Stanford through the Bioengineering department (Table 1). These courses were limited to students within the given departments and not available for all life science major students. The survey also looked for the presence of bioethics courses offered at the undergraduate level and found that each university offered at least one bioethics focused course. Some universities even had specific bioethics courses offered in multiple departments, however only one appeared to address biosecurity topics. Though the survey is not statistically significant, I believe it provides a snapshot of the bigger issue identified in the 2008 surveys that still exists today.

Table 1: Current Undergraduate Course Offerings on Biosecurity in Life Science Programs

Academic Institution	Course on Biosecurity	Department	Course Name
UC Los Angeles	Exists	Epidemiology	CM175 Terrorism, Counterterrorism, and Weapons of Mass Destruction
UC Berkeley	Does Not Exist	-	-
UC Davis	Does Not Exist	-	-
Stanford	Exists	Bioengineering	BIOE122 Biosecurity and Bioterrorism Response
Johns Hopkins	Does Not Exist	-	-
Princeton	Does Not Exist	-	-
University of Virginia	Does Not Exist	-	-
MIT	Does Not Exist	-	-

Importance of Undergraduate Education:
The scientific community needs to be equipped with the ability to do their part in protecting global health security. Incorporating biosecurity topics as part of life scientists' undergraduate education has the potential to be highly influential on future generations of scientists' values and practices. Just as our core individual ethical values develop in us from a young age, scientists' values and practices are molded beginning early on in their careers, starting with their education. As science and technology continue to advance and biosecurity issues and risks remain largely unknown, it is important to cultivate a culture of responsibility in the scientific community to ensure proper precautions are continually taken and that communication with the security community is kept flowing.

Undergraduate life science programs are populated by many young, fresh minds eager and ready to learn as they prepare themselves to become the future generation of working scientists. After completing undergraduate programs, some students go on to receive PhD's, Masters degrees, or special certifications, while some go directly into the workforce. Life scientists can be found working in academia, industry, organizations, government positions, and many other areas across the workforce, all of which have their own specific trainings and practices. Regardless of their careers, almost all hold a bachelor's degree in some form of life science specialty. Therefore, introducing biosecurity at the undergraduate level would ensure that all life sciences students graduate and enter the next step in their careers with at a least basic level of awareness of the issues, their responsibility, and the role they can play.

It is important to foster a scientific community based on a culture of responsibility who are aware of the possible implications their research could have on society. Instilling awareness at such an early stage is important so that a core value of moral obligations is established in young

scientists. They then can enter the workforce and spread awareness to practicing scientists that did not have the same educational opportunities when they were undergraduates.

Introducing this topic at the undergraduate level, during which many students are unsure of their future career paths could also inspire young scientists to pursue a biodefense policy focused career path. A similar outcome was seen with physicists and nuclear scientists shifting to security based research and careers after World War II. As science and technology continue to advance, the future of global health security requires responsible scientists, informed policy architects, and good collaboration between the two groups, all of which would be aided by developing undergraduate education in biosecurity.

Possible Education Programs:

In order to ensure a responsible scientific community, universities need to build a foundational understanding of an array of biosecurity topics. A thorough biosecurity education curriculum, as suggested by the AAAS[18], includes:

1.) Definitions of dual use and the implications of current and emerging technologies
2.) Case studies
3.) Laws and international obligations (ex. the BWC)
4.) History of Bioweapons and Biosecurity
5.) Professional responsibility and Scientists' public responsibility
6.) Ethical decision making
7.) Ways to communicate research activities to other scientists and the public
8.) Risk and Benefit assessments of their research

The elements of this curriculum can be promulgated by employing online resources and collaborating with colleagues, including organizations and agencies, faculty can develop undergraduate biosecurity coursework and can incorporate it into life science education programs in a multitude of forms. Some recommendations on actions that can be taken are listed below:

1.) New Biosecurity Courses

Biosecurity specific courses could be added to the list of elective courses offered to life science majors. A seminar-style format would provide students with information from a multitude of speakers who can address biosecurity topics from different perspectives. The seminars could also be accompanied by discussion sections at the end of the presentations to allow the students to further engage with the topics. Undergraduate life science students are already offered the opportunity to take seminar courses on a variety of topics that count as credit towards their major, so adding seminars that focus on biosecurity topics would be a feasible option. A seminar format is favored over a traditional lecture series course because seminars provide an array of perspectives and ensure student engagement. The speakers could be chosen to give the students a full picture of biosecurity in the life sciences, including speakers who address the history of bioweapons, the history of conventions and policies dealing with biosecurity, specific current and past dual use research issues, and future implications of biosecurity policies on the life sciences. The most crucial part of effectively implementing these seminars will be ensuring that the speakers are passionate and knowledgeable on the how the issue of biosecurity pertains to life scientists. Possible speakers could come from National

Laboratories, agencies such as the FBI and Centers for Disease Control (CDC), biotech start-ups, and professionals from the government that deal with implementing biosecurity polices.

2.) **Adding Biosecurity modules into existing biology courses**
Introducing biosecurity topics into existing biology courses would provide life science students with the opportunity to directly correlate biosecurity with certain biology topics. Though, introducing biosecurity with direct relation to the science is important, it would be difficult for lecturers to dedicate sufficient time to fully address the history and importance of biosecurity. This method would likely be limited to a few slides or one lecture within the life science course because of already packed curriculums. This is not to say this shouldn't be done, but this method should be accompanied by biosecurity specific courses to fully engage students with the topic.

3.) **Incorporating Biosecurity topics into existing bioethics courses**
Because many bioethics courses already exist and there is a close relation between biosecurity in the life sciences to bioethics, biosecurity topics could readily be incorporated into existing bioethics modules. However, the same issue of time comes up. Bioethics course curriculums already have a long list of traditional topics they must address, so there would have to be a strong movement to convince lecturers that biosecurity topics deserve the time in their courses. Though some lecturers would be willing to the find the time to incorporate biosecurity, not all would, nor would all have the proper knowledge to do so in a way that effectively introduces and engages the students on the issues. Biosecurity most certainly involves some bioethics thinking, but once again this method would be better if accompanied by a biosecurity specific course.

4.) **Online Courses**
Online modules are generally inexpensive, easy to deliver to a wide audience, and allow for the use of a variety of teaching methods. Online courses could utilize live seminar streaming, discussion forums, and uploaded recorded videos, allowing researchers, lecturers, and students from across the world to be brought together. These courses could not only be offered to undergraduate life science students, but they could also be utilized by faculty and practicing scientists to enhance their education on biosecurity. Online courses could also be used to educate life science lecturers giving them the ability to better incorporate certain aspects of the topic within their own courses.

Any of these methods could serve to help increase the undergraduate education of life science students on biosecurity, but all will require some faculty members to step up and dedicate time to developing new, thorough, and stimulating biosecurity curricula.

Moving Forward
Devising metrics to measure the effectiveness and impact that these education programs have on biosecurity will be difficult. Student surveys can be given to help tailor and adjust courses, certification programs can be created, and biosecurity standards could be inserted into life science degree requirements, but the most indicative demonstration of impact will be seeing an increase in the presence of life scientists in biosecurity discussions. True success will be

illustrated in the coming years if we see an increase in discussions on biosecurity within the scientific community itself, as well as an increase in discussions between the scientific and security communities. However, in order to see a significant change, national and international networks must work together to evaluate, improve, and implement these programs across the world because biosecurity is ultimately a global issue.

Providing the life sciences with biosecurity education early on will equip the future generation of scientists with the ability to shape future policies, adapt to future biosecurity issues, and throughout their careers proactively seek out further biosecurity education opportunities.

As science and technology continue to move forward with the outlook of improving society and human health, scientists must be enabled to do their part to take into consideration the benefits and risks of their research. Granted there is no way for scientists to predict the future and they cannot be expected to predict the capabilities of emerging, convergent technologies, but they must realize they play an important role in promoting the practice of responsible science that protects global health security.

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