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Motivating Proactive Biorisk Management

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Scholars and practitioners of biosafety and biosecurity (collectively, biorisk management or BRM) have argued that life scientists should play a more proactive role in monitoring their work for potential risks, mitigating harm, and seeking help as necessary. However, most efforts to promote proactive BRM have focused on training life scientists in technical skills and have largely ignored the extent to which life scientists wish to use them (ie, their motivation). In this article, we argue that efforts to promote proactive BRM would benefit from a greater focus on life scientists' motivation. We review relevant literature on life scientists' motivation to practice BRM, offer examples of successful interventions from adjacent fields, and outline ideas for possible interventions to promote proactive BRM, along with strategies for iterative development, testing, and scaling.

Keywords: Biorisk management, Biosafety, Biosecurity, Dual-use science, Bioethics, Psychological impacts

Introduction

Life science research can pose risks of harm involving biological agents. These can include harms from accidental release or exposure (biosafety risks) or deliberate misuse (biosecurity risks), or from sharing "dual-use" research information that might enable others to accidentally or deliberately cause harm.[1] We will refer to these risks collectively as *biorisks*, and their identification, assessment, and preemptive mitigation as *biorisk management* (BRM).

Like any task, BRM requires both ability and motivation. By *ability*, we mean the knowledge and skill necessary for someone to successfully execute a behavior if they choose to attempt it. By *motivation*, we mean all of the internal psychological factors that lead them to make the attempt—the "why" of the behavior, rather than the "how."[2] When we refer to life scientists being motivated to practice biorisk management, we mean to refer to the complex collection of worldview, beliefs, attitudes, and other factors that make BRM seem worth practicing. For example, motivational factors might include judgments of the tangible and intangible costs and benefits of BRM, perceptions of one's likelihood of succeeding in performing BRM, perceived social norms regarding BRM, and any underlying beliefs in premises that might justify the value of BRM.[3]

Many of the motivational factors driving BRM practice rely on the existence of predefined rules enforced by external and internal oversight bodies. For example, life

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scientists might practice BRM to avoid penalties for failing to follow the rules. However, there are limits to external enforcement. Biorisk management sometimes depends on the voluntary choices of life scientists and staff in situations where rules cannot be realistically enforced or do not yet exist.[4]

In these situations, many experts have called for life scientists to practice biorisk management *proactively*—that is, without the need for enforceable external oversight as a source of motivation. Consider 3 hypothetical scenarios of proactive biorisk management:

1. An academic life scientist is working in the laboratory alone on a weekend. There is virtually no chance that she will be observed by anyone else, but she still wears the required personal protective equipment and follows safety protocols.
2. A researcher is leaving the laboratory after a late night of work. He is usually the last to leave, but as he starts to walk out, he notices a recently arrived visiting scientist whose work is unfamiliar to him. The visiting scientist looks stressed and is working on something at the laboratory bench. The researcher approaches the visiting scientist to say hello, learn his name, learn about his project, ask him how he's doing, and offer his support if he needs anything. The researcher asks his principal investigator about the visiting scientist the next day.
3. As they are designing an experiment to test a novel antiviral therapy, a team of life scientists realizes that others might be able to use their technique to enhance the virulence of existing pathogens. No rule requires them to do so, but they decide to pause the work and contact the National Institutes of Health Office of Science Policy for advice about how to proceed.

By definition, proactive biorisk management requires a source of motivation beyond compliance with external oversight. However, much existing guidance and literature on promoting proactive biorisk management fails to specify this presumed source of motivation and instead focuses on training technical skills.[5-15] The lack of research and guidance on motivating proactive biorisk management is particularly concerning because many life scientists may lack a source of motivation to consider the risks of their work beyond compliance with external rules.[16-18]

To effectively promote proactive biorisk management, we need to expand efforts beyond ability-focused concepts like "training," "educating," and "awareness-raising" to include concepts like "motivating," "reframing," "persuading," "engaging," and "inspiring." This should not and does not need to be deceptive, overbearing, or unethical. Skilled teachers engage and inspire their students to develop a desire for knowledge. The same should be true for anyone seeking to engage life scientists in proactively managing biological risks. For example, training programs could include compelling explanations of the seriousness of dual-use concerns alongside examples of scientists who demonstrated foresight in anticipating those concerns.

In this article, we review arguments for the importance of proactive biorisk management, and we survey existing literature that suggests that many academic life scientists in the United States may lack strong motivation to practice it. We then contrast existing guides to biorisk management, which tend to focus on knowledge and skills, with literature from social psychology and the study of "safety culture," which conceptualizes motivation using variables such as social norms, beliefs, and goals. We offer 3 examples of how this literature might inform solutions to concrete challenges in biorisk management. We end with reflections on implementing a research and practice program to promote proactive biorisk management at scale.

Safety and Security Challenges and Need for Proactive BRM

The challenge of biorisk management is particularly salient, given the current COVID-19 pandemic. There has been debate over whether the SARS-CoV-2 virus first infected a human in a wet market in the Wuhan province of China, a nearby research laboratory, or another location.[19] Regardless of the origins of COVID-19 and SARS-CoV-2, scholars have argued that human error and deliberate misuse in research laboratories both constitute serious pandemic threats[20-22] and that dual-use research can create biosafety and biosecurity risks that are comparable in magnitude.[23,24]

Biorisks are managed through a "web of prevention" involving institutional, national, and international policies; tools and technical standards of practice; and social norms.[25] However, risky situations can and do arise in day-to-day laboratory work. Individual life scientists exercise a great deal of freedom in their approach to these situations because there are typically many possible experimental paths with different degrees of risk for achieving a scientific goal, and because external observers often cannot see their choices and reward or punish them accordingly.[4] This may be particularly true in cutting-edge life science research, which can create novel risks that have not yet been categorized or characterized within policies or technical standards but for which life scientists may have specialized expertise.[26-30]

To manage biorisks when external rules are unenforceable or nonexistent, many experts have called for life scientists to practice proactive biorisk management as part of a "safety culture" or "culture of responsibility."[27,31-36] Some have used the latter term in a way that is similar to proactive BRM.[37,38] However, "culture" is an extremely broad concept that, in a biorisk management context, is often used to refer not only to life scientists' motivation, but also the formal policies and management systems that surround life scientists.[37] While these factors are certainly important, we focused our research on the factors that motivate scientists in situations where formal policies and management systems do not yet exist or are not enforceable.

This does not mean that life scientists are the sole cause of risks or that they are solely responsible for managing them. However, they are in a powerful position to take initial action. Efforts to involve frontline workers in safety risk management have shown promise in a range of fields, including aviation, healthcare, and nuclear power, by equipping and inspiring workers to speak up when they notice something unusual.[23,35,39] It may be particularly valuable to engage life scientists in situations where policies do not yet exist, because their observations can inform the development of new policies and procedures.[40,41]

Life Scientists' Motivation to Practice Proactive BRM

Background

Biorisk management is important for preventing accidental and deliberate harm that might be caused by life science research. External oversight can motivate life scientists to practice BRM by convincing them that they will risk personal costs (such as losing their jobs) if they fail to properly manage risks, or that they will be rewarded for the proper management of risks. But in situations where external oversight rules are difficult to enforce or nonexistent, what else will motivate life scientists to practice BRM?

It can be helpful to reframe this question by asking, "What would life scientists need to *believe* and *value* in order to practice BRM proactively?" For example, they might need to believe that practicing proactive BRM will keep them or others safe from biological hazards, protect their field from bad publicity, or save time with laboratory management in the long run.[17] They might also believe that practicing proactive BRM is an interesting intellectual challenge or an expected part of being a responsible life scientist.[42]

Beliefs about the perceived costs and benefits of behavior are central to most theories of motivation.[3,43,44] As a simple approximation, people want to engage in a behavior when they believe that they can successfully perform it and when they believe that the benefits to them outweigh the costs relative to some valued set of goals. Psychologists have cataloged many goals that are salient in work environments, such as career progress,[45] belonging to a social group,[46,47] acting in alignment with a personally valued social norm or identity,[48,49] and helping others.[50] If life scientists believe that BRM serves these goals, they may be willing to practice it proactively.

However, some life scientists may also hold beliefs that make them unmotivated to practice BRM. For example, they might believe that certain risk management practices are difficult, time-consuming, unpopular, useless, or even harmful to their careers and/or society because of their perceived effects on the progress of scientific work. This is not a particularly surprising possibility; research aligns with common intuition to suggest that employees in a range of fields are often disengaged from outside efforts to promote workplace safety.[51-53]

We have little empirical data on life scientists' beliefs about BRM or their resulting motivation to practice it.[37] However, some initial impressions can be drawn. The literature that does exist suggests that many life scientists are uninformed, apathetic, or resistant to practicing various forms of BRM. We review literature on 3 topics: life scientists' general motivations for choosing their career as a backdrop for their potential motivation to practice BRM, their engagement with and beliefs about current biosafety rules once they have begun their research career, and their beliefs about dual-use risk management. There is a notable lack of research on life scientists' beliefs regarding the risks of deliberate theft or misuse of laboratory materials or information.

Career Motivations

In general, life scientists do not consider biorisk management as part of their motivation to enter the field. Interviews and focus group studies of life scientists have found a range of reasons why people choose to enter, including enjoyment of discovering new scientific knowledge, career mobility, enjoyment of problem-solving, and the desire for independence in their work.[54,55] Once they have entered the field, academic scientists generally face strong career pressures to "publish or perish."[56] Scientists are also somewhat motivated by the desire for prestige in their communities,[57] and scholars have noted the role of prestige in driving scientific productivity.[58] None of the motivations described here are necessarily associated with a desire to reflect on and manage potential risks.

In 2 studies,[59,60] researchers found broadly similar patterns when interviewing academic life scientists about their perceptions of the societal and ethical issues involved in their work. They found that life scientists were often required to justify the societal value of their work for external grants and publications, but that many were simply unaware of potential societal concerns about their work, believed that such concerns were irrelevant to their research, believed that they were incapable of managing concerns, and/or deprioritized societal concerns to focus on conducting rigorous research that contributes new knowledge to the field.

Engagement With Laboratory Biosafety Rules

At some point, most life scientists will work in a laboratory setting where they are expected to follow safety rules. However, surveys of US laboratory scientists have found that large fractions of respondents report apathy and/or competing priorities regarding laboratory safety rules. For example, in a series of annual surveys of laboratory safety staff and scientists at a US national conference, the most commonly cited barrier to improving laboratory safety (with almost 50% of each group agreeing) was "competing priorities," the second-most commonly cited barrier was "apathy," and the fourth was "time and hassle factors."[61] Schroder et al[16,17] similarly found "time and hassle" and "apathy" to be the largest self-reported barriers, with one scientist writing, "If I could have selected apathy 3 times over, I would have." They also found that 15% to 30% of laboratory scientists (the percentage varied across academia, industry, and government) believed that current safety rules negatively impacted their productivity and/or interfered with the scientific discovery process. These numbers may, in fact, be optimistic. Keiser and Payne[62] provide evidence that respondents to workplace safety surveys deliberately skew their responses to manage their social impressions.

Ultimately, apathy and competing priorities may not only affect the quality of compliance with preventive safety and security rules, but also the quality of response in the event of a laboratory accident. Across 3 studies, 25% to 38% of laboratory researchers claimed to have experienced a laboratory accident but did not report it.[16,63,64] Survey findings published in 2016 flagged human error as a central cause of 78% of laboratory-acquired infections in biosafety level (BSL) 3 and 4 laboratories, closing bluntly with: "In conclusion, there is still a need to implement a culture of biosafety in the life sciences, rather than strengthen regulations."[36]

Beliefs About Dual Use

In addition to direct risks from laboratory accidents, some life science research projects could also provide others with the intellectual or physical tools to accidentally or deliberately cause harm. Identifying and managing the risks of this dual-use research is difficult, and the challenge is only increasing with the scale and sophistication of the life sciences.[27,31,32,65]

How do life scientists think that dual-use research should be managed, and are they motivated to manage it themselves? Answering these questions is challenging for several reasons. First, there are even fewer studies on life scientists' beliefs about dual-use issues than about biosafety, and these studies are mostly qualitative analyses of small samples.[18,42,66] Second, life scientists' awareness of dual-use

Table. Common Arguments by Life Scientists Against Regulation of Life Science Research With Dual-Use Potential

Argument	*Description of Argument*	*Source*[a]
"Dual-use risk is minimal"	Dual-use research does not pose a serious risk of misuse	Dando and Rappert (p. 13), NRC (p. 143)
"Replication and weaponization are too difficult"	Dual-use research is too difficult for others to replicate and weaponize to be a substantial source of risk, particularly compared with other options for bad actors	Dando and Rappert (p. 17), NRC (p. 144), Engel-Glatter and Ienca (p. 4)
"Research can't be stopped"	Efforts to control information are useless because life science research will be carried out and disseminated by someone at some point	Dando and Rappert (pp. 14-16), NRC (p. 148), Engel-Glatter and Ienca (p. 3)
"Bad actors can't be stopped"	Efforts to mitigate risk are useless because bad actors cannot realistically be prevented from using research to cause harm	Dando and Rappert (pp. 8, 15), NRC (p. 148)
"Research is necessary for countermeasures"	Dual-use research should be performed because the resulting knowledge is necessary for the development of countermeasures to the risk under study	Dando and Rappert (p. 14), NRC (p. 147), Engel-Glatter and Ienca (p. 5)
"Research is necessary for other valuable technologies"	Dual-use research should be performed because the resulting knowledge is necessary for the development of other valuable life science technologies	Dando and Rappert (p. 16), NRC (p. 147), Engel-Glatter and Ienca (p. 4)
"Research is necessary for awareness-raising"	Dual-use research should be performed in order to demonstrate its potential to the world and raise awareness for proper risk management	Dando and Rappert (p. 14)
"No agreement about what is dangerous"	Risk mitigation is impossible because scientists and scholars cannot agree on what is dangerous enough to merit concern	Dando and Rappert (pp. 18, 20)
"Life scientists are unlikely to be bad actors"	Life scientists tend to enter their field to improve human health and wellbeing, which makes them unlikely to want to misuse biology for harm	NRC (p. 148)
"Risk management will slow down the whole field"	Efforts to manage dual-use risks from research will slow current work and disincentivize future work	Dando and Rappert (p. 20), NRC (pp. 146, 147), Engel-Glatter and Ienca (p. 4)

[a]Drawn from Dando and Rappert,[18] National Research Council (NRC),[42] and Engel-Glatter and Ienca.[66]

issues may be in a state of flux at the time of this publication as a result of recent controversies related to research being performed near the site of the first identified COVID-19 cases.[19,66] Third, unlike laboratory biosafety, there is little consensus on the best practices for dual-use risk management.[32] Finally, beliefs about dual-use risks and beliefs about their proper management might be only loosely coupled. For example, life scientists might disagree about the prevalence and severity of dual-use risks, and they might independently disagree about whether those risks require more or less heavy-handed efforts at risk management or whether successful management is even possible (see Table).

Therefore, we do not make strong claims about whether life scientists are currently meeting any normative standards of engagement with dual-use concerns, and we do not assume that concern about dual-use risk translates straightforwardly into an endorsement of certain risk management strategies. Instead, we note several themes that consistently emerge across multiple studies to outline some broad claims about life scientists' opinions and feelings about dual-use risks.

The first theme is that life scientists typically express concern about the potential harms of dual-use research, but they are frequently opposed to restricting it for a variety of reasons, as summarized in the Table. The arguments on display illustrate a variety of beliefs that may affect life scientists' motivation to consider dual-use risks. We emphasize that the proper management of dual-use research is highly complex and contentious. For example, arguments about the inevitability of research, the utility of research for awareness-raising and countermeasures, and the difficulty of constraining bad actors remain topics of extensive debate.[67,68] Our goal is not to evaluate the merits of each argument, but rather to contribute to a sketch of life scientists' opinions about the topic.

Second, life scientists strongly prefer to manage dual-use risks themselves, rather than to follow external oversight.[42,66] There are several possible explanations for this finding. Some scientists likely support self-regulation because they believe it is more effective and/or less burdensome than risk management as performed by external regulators. Indeed, this position was taken by the authors of the original National Research Council report that laid many of the foundations for current US dual-use policy: "A system of review based in scientific self-governance can, we believe, effectively address the security risks without discouraging scientists from taking part in important biodefense research."[27] How this occurs in practice is not well understood. In a 2007 survey, 15% of life scientists self-reported taking proactive steps to manage a potential dual-use risk of their own work, but the survey had only a 16% response rate and may have disproportionately attracted respondents who were interested in dual-use issues.[42]

Some life scientists may not be particularly in favor of self-regulation *or* external regulation, but state a preference for self-regulation to avoid being forced to modify their work. Like other scientists,[69] life scientists also strongly support norms of open science and information sharing. They tend to strongly resist approaches to dual-use risk management that involve controlling the ability to publish.[18,42,66] Indeed, some life scientists in one focus group study endorsed the idea that there is simply no research that is "inappropriate for study."[42] Life scientists have also consistently noted in interviews that they already feel "overregulated" and that dual-use risk management tends to run counter to their own career incentives to publish high-profile research.[18,42,66]

In addition, virtually all the arguments listed in the Table apply equally to the self-regulation or external regulation of research. Put simply, if dual-use risks are minimal and/or unstoppable (arguments 1-4), if dual-use research has benefits that outweigh the risks (5-7 and 10), if there is no agreement about what is actually dangerous (8), or if life scientists are unlikely to be bad actors (9), then both self-regulation and external regulation appear unnecessary at best, or potentially harmful at worst.

Life scientists also frequently appear to conceptualize dual-use research as solely involving a small set of pathogens and experiments. This may be due in part to US government guidelines on "dual-use research of concern," which defines the term broadly but flags a small set of pathogens and experiments for required review under certain conditions.[70] As a result, life scientists, even those aware of the term "dual use," tend to believe that their own work cannot be dual use, potentially reducing their motivation to consider its risks.[18,42,66] Accounts of the historic 1975 Asilomar Conference on Recombinant DNA described a similar pattern of life scientists being reticent to directly acknowledge the risks of their work and motivated to practice self-governance to avoid external oversight.[71]

Taken as a whole, these initial findings paint a mixed picture of life scientists' motivation to manage the potential dual-use risks of their work. However, it is essential to recognize that the life scientists in these studies may have different ideas about what "management" entails, and that this may affect their risk perceptions. Some life scientists may see "managing" dual-use risks as a euphemism for blocking research entirely. Others may be aware of lighter-touch options, such as redesigning experimental approaches or de-emphasizing certain points in public communications. Research on the phenomenon of "solution aversion" suggests that people tend to downplay the seriousness of a problem if they believe that there is only one solution and they find it unappealing.[72,73] More research is needed to untangle the dependencies between life scientists' beliefs about dual-use risk and their beliefs about the available options for managing it.

Efforts to Promote Proactive BRM Focus on Skills Over Motivation

We have argued that motivation is essential for adopting and practicing proactive BRM and have reviewed research suggesting that many life scientists may lack this motivation. This suggests that efforts to train life scientists in skills of proactive BRM should also address motivational issues. Indeed, decades of research in psychology and education have found that lessons and persuasive messages are significantly more likely to cause long-lasting changes in knowledge and behavior when the receiver is sufficiently motivated to think deeply about them.[74,75]

However, BRM guidebooks and articles tend to focus on training life scientists in the skills of identifying and mitigating risk, and they mostly ignore sources of motivation other than compliance with rules. For example, the US Centers for Disease Control and Prevention (CDC) authoritative biosafety manual *Biosafety in Microbiological and Biomedical Laboratories*[5] and the International Organization for Standardization (ISO) biorisk management standard[6] contain little mention of motivational issues. The most recent World Health Organization biosafety manual contains scattered mentions of the importance of a "safety culture"[7] and references an accompanying monograph containing only 2 pages of broad recommendations to practice "effective communication," "active engagement," and "encouragement" of staff. There is a similar lack of detail in guidebooks and articles describing best practices and recommendations for biosafety,[8,9] biosecurity,[10-12] dual-use risk management,[13,14] and BRM as a whole.[15]

Revealingly, a number of documents seem to mischaracterize the creation of a "culture of safety" solely as a matter of skill training, or they use the term "training" as a placeholder for a lack of detail about how exactly to engage life scientists. For example, the CDC's biosafety manual contains scattered mentions of the concept of a culture of safety, and notes that it requires "a proactive rather than a reactive approach," but describes this "culture" as created primarily through "integrating a risk management process into daily laboratory operations," providing "information, resources, and training," and developing "habits and procedures through training and competency checks" among life scientist staff.[5] But it is not clear how processes and training will cause life scientists to care more about BRM or to willingly raise the alarm about novel concerns.

Similarly, the University of Texas at Arlington's biosafety manual opens with a full page dedicated to a statement from the CDC about the importance of a culture of safety, but after that it only mentions the term one more time, arguing that principal investigators "must instill a positive attitude and awareness of the Culture of Safety in their laboratory workers through training and adding discussions concerning laboratory safety in their regularly scheduled laboratory meetings."[76] Without further explanation of their content, mandatory skill training and onerous discussions based on transparent external requirements seem just as likely to annoy life scientists as to enlighten them about the value of biorisk management.

Although less frequently emphasized than skill training, some groups have also used historical or fictional case studies to promote proactive BRM. For example, outreach efforts to life scientists from the Federal Bureau of Investigation's Weapons of Mass Destruction Directorate, Biological Countermeasures Unit, and the Engineering Biology Research Consortium use historical examples of biological catastrophes and near misses to motivate life scientists to engage with dual-use issues in their work.[77,78] Similarly, Kahn[79] suggests that biosecurity could be "embedded into the culture of the life sciences" by requiring the National Institutes of Health to require grantees in relevant fields to take a course covering "a brief history of bioterrorism, the Biological Weapons Convention, and key findings and recommendations of the Fink Report."

In theory, historical case studies could motivate life scientists by clarifying that biological catastrophes from life science research are a real and horrific possibility. However, to the best of our knowledge, no study has evaluated the effects of historical case studies or fictional scenarios on life scientists' beliefs or behavior. Given the personal motivation and career incentives that they experience to get their work done, and the relative infrequency of biological catastrophes, it is not hard to imagine that some life scientists think historical case studies do not apply to their own work, or that biological catastrophes are so rare that they are not worth worrying about.

Some biorisk management texts do at least briefly mention practices for promoting BRM that have a clearer motivational aspect. For example, the CDC's biosafety manual[5] and Higgins et al[80] argue that life science research institutions should incorporate nonpunitive mechanisms for reporting safety and security concerns, and Gaudioso et al[81] note that "From the authors' personal experience, when a director attends a biorisk management training course with the workforce, instead of just mandating it for subordinates, he or she demonstrates leadership's commitment and vision better than a memo could ever communicate."

In our view, these examples are a start, but they merely scratch the surface of efforts to change culture. For example, leadership could:

- provide more detailed information about the baseline probabilities and consequences of harmful incidents in other laboratories in order to put risks in context
- prompt staff to actively elaborate on the personal and professional consequences of a serious incident, including personal injury, harm to colleagues and loved ones, disrupted scientific progress, reputational harm to the institution, and derailed career plans
- actively celebrate the reporting of safety and security concerns, not just refraining from punishing it
- solicit and reward ideas from staff for improving biosafety and biosecurity through engineering and/or changes to policy and practice

- publicly praise their safety and security practices to external audiences
- privately praise influential and respected laboratory members for their safety and security practices and ask them to continue setting an example for their peers

We discuss frameworks for considering and developing other possible approaches in more depth later, but our larger point is that there is much existing work proposing or describing the implementation of management systems and training programs, but little evaluation of how life scientists subjectively experience them or whether their motivation to practice BRM actually changes as a result.[82] A 2020 critical review of laboratory-safety research agreed: "Given the likely impact of individual biases, ensuring perfect access to information and training […] and making equipment available is not likely to change outcomes without a better understanding of the psychology of safety decision-making. […] However, to date, the champions for safety have been natural scientists and engineers whose research expertise is not in social science methodology and who may be unfamiliar with important and relevant psychological constructs."[83] We seek to remedy this situation by bringing a more psychologically informed perspective to biorisk management.

Insights From Social Psychology and Safety-Culture Research on Motivation

Motivation is a broad and interdisciplinary concept that has been productively studied by a range of disciplines under the umbrella of the behavioral sciences, including economics,[84] sociology,[85] organizational studies,[86] neuroscience,[87] and anthropology.[88] However, we believe that for risk management professionals seeking to motivate life scientists to practice proactive BRM, one promising starting point is social psychology, which is "the study of social behavior, especially of the reciprocal influence of the individual and the group with which the individual interacts."[89] Social psychology models human behavior using intuitively familiar concepts and then tests and applies its models with quantitative rigor and a focus on practical utility.[90] Its theories and methods are foundational in many applied psychology fields, including organizational and work psychology, marketing, aspects of educational psychology, political psychology, and health psychology.[91]

In this section, we outline a simple social-psychological view of human behavior. While necessarily brief, our review highlights a host of factors that are largely neglected by current approaches to promoting proactive BRM. We expand on some of these factors in the examples in the next section.

Social psychologists tend to explain human behavior in terms of internal psychological variables such as beliefs and goals.[3,92,93] Collectively, these variables can be said to constitute a person's subjective worldview—their mental models of themselves and the world around them, their own desires, and their strategies for achieving those desires. For example, a laboratory technician who voluntarily chooses to double-check a freezer inventory might do so because they believe that the personal costs of doing so are reasonable, because they believe that they will be appreciated by their peers, and because double-checking the inventory satisfies a desire to see themselves as careful and detail oriented.

As people carry out actions, they affect the social environment for others, creating the conditions for reciprocal relationships, social norms, and group coordination. For example, a principal investigator in a laboratory may choose to highlight the importance of inventory management in a laboratory meeting because they believe that laboratory staff value it and expect it to be mentioned. This might cause other laboratory members to infer that the principal investigator expects them to practice inventory management, setting a social norm that affects their behavior. In turn, this could reinforce the principal investigator's original perception that inventory management is valued in the laboratory.

In this view of the social world, people are not independent actors who will practice biorisk management once programmed with the proper skills. Instead, people actively make sense of their social environments based on (potentially mistaken) beliefs, they pursue goals in light of these beliefs, and they affect each other in complex ways that can become self-reinforcing. Social psychologists often seek to create positive feedback loops for long-term change using interviews, surveys, and randomized experiments to study and intervene in the beliefs that people infer from their environments.[94,95] For example, studies have improved interpersonal relationships by inviting people with low self-esteem to reinterpret compliments from their partners as sincere[96] and have improved academic outcomes by inviting students to reinterpret the experience of academic difficulty as a normal part of learning, rather than as a sign that they are incapable of learning.[97]

Insights from social psychology have already been used to promote ethical research practices in ways that might generalize to biorisk management. For example, in a study published in 2020, social psychologists sought to encourage laboratory scientists to establish formal policies for determining the order of authorship for future papers.[98] They developed a "lab-embedded discourse intervention" to promote open discussion about the topic, but they discovered in pilot work that principal investigators who were opposed to the idea could sometimes intentionally or unintentionally pressure their staff to withhold dissenting views. To disrupt this dynamic, the authors of the study recruited junior laboratory members as "peer mentors" to colead each discussion, and found large effects 4 months later on laboratory members' self-reports of using a formal authorship policy. The lessons of this study hold promise for dealing with life science principal investigators who are resistant to biosafety and biosecurity reform in their laboratories.

In the domain of biorisk management, principles and perspectives from social psychology can currently be most clearly seen in research and recommendations for promoting a safety culture.[33,99] The concept of safety culture originated in models of organizational culture by Schein,[100] who was originally trained as a social psychologist. Both "organizational culture" and "safety culture" broadly refer to the artifacts, behaviors, and worldviews that are shared by members of an organization, but these constructs are defined by scholars in widely differing ways, and the field generally lacks consensus or evaluation of frameworks beyond tests of face validity.[101]

Nevertheless, safety culture scholars have successfully drawn attention to the ways in which safety is valued or devalued in organizations, and they have been influential in a range of industries, such as aviation, nuclear power, industrial chemistry, and healthcare.[23,102-104] Because of their focus on shared perspectives across a group, safety culture reform efforts tend to focus on promoting social norms as an intervention method. Some efforts have a more systemic, transformative character, such as attempts to create "high-reliability organizations" by intervening simultaneously in all parts of an organization.[39] They have been compared to "moving from directing one play to another"—ambitious but also difficult and expensive.[105] Other change efforts are more targeted to 1 or 2 types of individuals in an organization and tend to have a lighter touch, such as having leaders publicly and credibly endorse efforts to promote safety in their organizations.[33,99,106] We discuss both approaches later, noting that social psychology offers a wider range of intervention methods that can be used to promote proactive BRM.

Psychologically Informed Approaches to Motivate Proactive BRM

In this section, we elaborate on the set of examples of proactive BRM from the Introduction. For each example, we sketch current barriers to practice and then suggest an approach inspired by existing social psychology research. When possible, we also offer potential examples of this idea already being implemented or explored. We focus here on academic life science research in the United States, although the ideas described could extend more broadly.

Example 1: Listening Tours for Proactive Biosafety

Workplace safety researchers argue that laboratory scientists and their institutional biosafety staff should maintain strong working relationships.[33,99] However, scientists can sometimes be guarded about interacting with biosafety staff to avoid bureaucratic barriers to their work. Scientists can also sometimes overestimate biosafety staff departments' levels of knowledge, capacity, and influence. This can lead to several problems. First, scientists can mistakenly offload responsibility for laboratory safety onto staff and fail to be proactive about safety themselves. Second, if scientists hold unrealistically high expectations of staff, and those expectations are violated, they could unjustifiably lose respect for staff.[33]

While providing more skill training and resources for biosafety staff may be necessary to improve their capacity in the long run, a social-psychological approach might focus on improving scientist–staff relations by preemptively correcting mistaken assumptions on both sides. One example approach could be for biosafety staff to conduct periodic listening tours with life science laboratories. Staff could join existing laboratory meetings to introduce themselves, assure laboratory members that they are not conducting an audit, and ask scientists to teach them about the safety risks involved in their subfield (not necessarily their particular laboratory). Staff could close the conversation by thanking the group and requesting advice on how to reduce the burdens of risk management and engage *other* life scientists about the importance of laboratory safety. This request is derived from a persuasion technique known as self-persuasion, which can be effective because it invites participants to actively generate a message that they themselves find persuasive.[107,108]

By positioning themselves as learners, biosafety staff members can accomplish several psychologically potent goals simultaneously. They can send the message that they are not omnipotent, frame scientists in a position of responsibility and authority regarding laboratory safety, and convey the potential for a friendly, collaborative relationship in the future. They also give life scientists concrete practice thinking about how their own work could be unsafe without fear of being audited, and may give staff valuable information about novel safety risks and ways of making risk management less costly.

One potential example of this approach in practice can be found at the University of Wisconsin, Madison, which oversees a large and complex life science research infrastructure. The University of Wisconsin institutional biosafety committee conducts outreach visits to life scientists with the goals of establishing caring and friendly relationships and positioning themselves as helpful supporters of scientists' own values of personal safety. According to staff reports, the upfront work of building relationships pays off later with smoother future interactions and a stronger safety culture.[109]

Example 2: Social Support Services for Proactive Biosecurity

Insider threats—when laboratory staff deliberately misuse biological agents, leak information, or otherwise compromise laboratory security—are a rare but frightening occurrence. A 2015 historical analysis of 93 biosecurity incidents at research institutions in the United States estimated that the relative risk from insiders was higher than the risk from outsiders.[24,110] Insiders can perpetrate crimes themselves or intentionally or unwittingly assist outsiders, and they might be scientists or other staff members who have access to laboratory facilities.

Insider threats are also difficult to combat.[111] After the 2001 US anthrax attacks, 4 national studies recommended strategies to address the problem, including increased physical security, more carefully controlled access to pathogens, and improved screening for personnel reliability.[34,111-113] Although valuable, these strategies are also controversial because they each suffer from security flaws and/or impose substantial costs on the ability of life scientists to conduct research.[114]

At least 2 of the 4 reports also emphasized the importance of a "culture of responsibility" in high-biocontainment government laboratories, in which life scientists proactively monitor each other for potential insider threats.[34,113] However, such a culture would likely be unpopular among many life scientists. Berger[110] noted that "concerns about policing peers or having the appropriate whistleblower protections have been raised by the scientific community for more than a decade." Few people wish to imagine the possibility that their colleagues could be potential criminals, much less level an accusation.

However, one key insight from social psychology is that the same behavior can be more or less appealing depending on the purposes or meanings in which it is framed.[94,115] Life scientists might see the act of monitoring their peers' behavior as caring, rather than accusatory, if it was done in a spirit of social support for personal stressors or other difficulties. In other words, peer-led social support services could give life scientists an alternate reason to practice peer monitoring that could help prevent potential insider threats while being less uncomfortable and directly benefiting those who are in need of support.

There are many drivers of insider threats, but personal difficulties and stressors, work conflicts, and/or social isolation often appear to play amplifying roles.[110,116] Personal stressors also amplify biosafety risks.[80] Institutional social support services such as mentorship and counseling may help staff manage these stressors, which could support staff wellbeing as well as biosafety and biosecurity. BSL-3 and BSL-4 laboratories at the US National Biodefense Analysis and Countermeasures Center and the National Institutes of Health already use such services as part of their personnel reliability programs,[80,117] and Gelles et al[116] argue that they play a critical role in mitigating insider threats.

Social support services are also scalable. Berger[110] notes that "most, if not all, major research institutions in the United States" already have some employee and student assistance programs. There is an increasing recognition that the competitive and stressful work environment of academia contributes to widespread mental health issues,[118] and many schools are already increasing their institutional support for mental health with on-campus resources.[119] Even so, more work is needed to integrate peer monitoring into social support services at research institutions. For example, scientists and staff might receive brief reminders of the existence of social support services along with messages dispelling any stigma around using or recommending them.

Example 3: Social Norm Approaches for Proactive Dual-Use Research Risk Management

Life scientists may have a valuable role to play in the "web of prevention" by proactively reflecting on whether their work creates novel dual-use risks. However, as noted earlier, surveys and interviews with life scientists in the United States, United Kingdom, and Switzerland suggest that many life scientists have never considered that their own research might be dual use, are leery of additional regulatory burdens slowing down their research, and are skeptical of attempts to control the advancement of science.[18,42,66] Representatives from academic institutions at a 2017 stakeholder workshop held by the National Institutes of Health on the 2014 US Dual Use Research of Concern policy concurred, noting that it was rare in practice for life scientists to proactively flag their own research as concerning.[109]

Indeed, the request being made of life scientists in managing dual use is substantial: proactively consider whether your own research projects could be misused to cause broad potential harm, and if so, submit them for further examination by an external body that may delay or even block your work. Nevertheless, there are scattered examples of life scientists proactively reporting dual-use concerns.[109,120,121] What can be done to encourage more life scientists to adopt this responsibility?

One promising set of possibilities involves advocating for a social norm in which the evaluation of dual-use concerns is seen as part of what it means to be a responsible and respected life scientist. Norms are among the oldest and most well-studied constructs in social psychology,[122-124] and a number of conceptual tools and methods can be brought to bear on the topic. We review 3 approaches, emphasizing that none are sufficient and that more research is needed to evaluate their potential.

One approach may involve a choice of language. Husbands[125] has noted that dual-use concerns are often framed through a lens of "security," a term that is alien to the lived experience of many life scientists, when they could also be viewed as "responsible science," or a more intrinsic part of the duty of a scientist. Social psychologists have found examples of small differences in language framing that can have surprisingly large effects on behavior via the subjective meanings that people make of their experiences.[96,126,127]

A second approach may involve pluralistic ignorance, the state in which individuals underestimate the extent to which their privately held views are shared within their group.[124,128] Research has found that when people are mistaken about the popularity of a belief or behavior that they privately hold, simply informing them of the true distribution of opinions can sometimes shift their perception of the norm and thereby change behavior.[129] Many life scientists already appear to endorse the idea of self-regulating dual-use concerns in surveys and interviews,[18,42,66] but it is unclear whether they are aware that other scientists like them share their views. Surveys could collect and share opinions about dual-use issues among life scientists to point out that support for self-regulation is more widely supported than people might individually expect.

A final approach might involve linking to existing norms of rigorous research. Scientists already strongly endorse a norm of "organized skepticism."[69,130] They recognize that even though they likely believe in the quality of their own work, science as a collective enterprise functions more effectively when they submit their work for peer review. By a similar logic, it might be argued that the life sciences will function more effectively when scientists avoid catastrophic dual-use risks, but that they need to submit their work to risk analysis by their peers to do this effectively. Program developers could use these arguments to convince life scientists to participate in networks of dual-use peer evaluation and to conduct novel research to inform biorisk management efforts.

The 3 approaches described could be operationalized in the form of brief, scalable online reading and writing activities modeled after the interventions used by social psychologists to trigger lasting behavior change.[94] For example, life scientists might be invited by their academic institution or professional society to complete survey questions about how they think dual-use concerns should be handled, and then shown empirical distributions of the answers of their peers. They might also be invited to write a response to a question like "How are dual-use concerns related to what it means to you to be a life scientist?" and shown vivid and representative examples of other responses from members of their field—an approach that has been successful at shifting beliefs at scale.[131]

Implementation

This section offers several suggestions for implementing a program of applied research and practice to promote proactive biorisk management among life scientists. These suggestions are intended to complement existing guidelines for creating a safety culture.[37,99] While these guides may offer helpful broad advice for quickly taking action across an institution, they tend to lack mechanisms for testing and feedback, which are critical for ensuring that programs are compelling for life scientists.

Specify Target Behaviors

To leverage the strengths of social psychology most effectively, it is important to clarify target behavioral outcomes. Biorisk management scholars and professionals should be more specific about operationalizing a "culture of responsibility" in terms of a set of broadly helpful behaviors, who should perform them, and under what circumstances. This is particularly true for managing the risks of novel and potentially risky research. As biorisk management scholar Sonia Ben Ouaghram-Gormley noted in 2020, "That should probably be the next priority for the National Academies in cooperation with their European and Asian counterparts: identify a decision tree to help scientists decide what to do when they hear about dangerous research."[132]

Seek to Understand the Social Environment With Surveys, Interviews, and Focus Groups

Context matters. The social environments and subcultures of life science departments vary, and the history of behavior change and culture change efforts is littered with unexpected flops and failed replications.[115,133-135] Effective interventions tend to be psychologically precise in their meaning and in the time and place of their delivery. They might look insignificant, but can feel significant because they resonate with people's lived experiences.[136]

Creating effective interventions therefore requires site-specific qualitative and quantitative data. As noted earlier, there is a lack of research on the beliefs of life science stakeholders regarding risks and risk management. New research will require funding and partnerships among social scientists, life scientists, and biorisk professionals. Researchers should observe, interview, and survey life scientists and neighboring groups, such as funders, publishers, regulatory staff, and institutional leadership. Researchers should pay particular attention to groups that are most important for establishing incentives and social norms for life scientists, such as funders, publishers, and professional societies. Researchers should also look for key moments in life scientists' careers that tend to establish perceptions of social norms, such as onboarding, laboratory meetings, biosafety officer interactions, conferences, and initial interactions with funders and publishers. These moments can create first impressions that persist over time, making them key sites for intervention.[46]

Start Small, Then Develop and Deploy Changes With Rigor and Sensitivity

Using their initial findings, researchers and program developers should rigorously pilot test interventions on a small scale and engage in dialogue with stakeholders throughout to avoid unintended meanings, backfiring, or other downsides.[115] Intervention development also need not be centralized or siloed. One promising approach may be for biosafety offices and life science departments to partner with social science departments in universities to develop and test more compelling biosafety training modules and then share their efforts through broader networks. For example, Arizona State University has been developing and freely sharing biosafety training videos in partnership with biorisk management scholars and the Association for Biosafety and Biosecurity.[137]

Offer Resources and Support to Sustain Existing Interventions and Create Conditions for New Interventions

Social-psychological interventions have been compared to seeds that need the right soil to thrive.[138] Even if an intervention resonates with someone personally, they might need additional resources or social support from the environment for it to stick. In a supportive environment, the right message can have outsized self-reinforcing effects, but in an inhospitable environment or from the wrong source, the most compelling message will have little effect.[139] Once again, program developers should be sensitive to differences in context. For example, a well-designed biosafety onboarding module might fall flat in a laboratory where the principal investigator ignores safety rules, and it may not be actionable in a laboratory that cannot afford appropriate personal protective equipment. This is one rationale for the more systemic change efforts recommended by safety culture guides.[33,99]

In addition to supporting existing interventions, resources and social support can also create the conditions for new intervention ideas to emerge. Funders can play an important role in this process. For example, they might follow the reproducible-science community model by partnering with publishers to release calls for applied biorisk management research that pairs life scientists and social scientists.[140] Research projects that qualify can be rewarded with higher chances of funding and/or publication. The International Genetically Engineered Machine (iGEM) synthetic biology competition can also serve as an example of a testbed for providing incentives for engagement with safety and security and encouraging interdisciplinary collaboration.[141]

Conclusion

As life science research and technologies continue to advance, the risks from accidental or deliberate misuse become more complex and difficult to anticipate, and the need for life scientists to practice proactive biorisk management only increases. We have argued that life scientists need to be motivated to practice proactive biorisk management and that social psychology offers some useful tools for conceptualizing and cultivating this motivation. These tools could help meet calls for a culture of responsibility that have only intensified over the last several decades, and could offer a productive complement to policy-focused approaches to biorisk management.

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References

1. Lewis G, Millett P, Sandberg A, Snyder-Beattie A, Gronvall G. Information hazards in biotechnology. *Risk Anal*. 2019; 39(5):975-981.
2. Griffin MA, Neal A. Perceptions of safety at work: a framework for linking safety climate to safety performance, knowledge, and motivation. *J Occup Health Psychol*. 2000; 5(3):347-358.
3. Ajzen I. The theory of planned behavior. *Organ Behav Hum Decis Process*. 1991;50(2):179-211.
4. Huising R, Silbey SS. Governing the gap: forging safe science through relational regulation. *Regul Gov*. 2011;5(1): 14-42.
5. US Centers for Disease Control and Prevention (CDC), National Institutes of Health. *Biosafety in Microbiological and Biomedical Laboratories*. 6th ed. Atlanta, GA: CDC; 2020. Accessed October 18, 2021. https://www.cdc.gov/labs/BMBL.html
6. International Organization for Standardization (ISO). *ISO 35001:2019 - Biorisk management for laboratories and other related organisations*. Published November 2019. Accessed October 15, 2021. https://www.iso.org/standard/71293.html
7. World Health Organization (WHO). *Laboratory Biosafety Manual*. 4th ed. Geneva: WHO; 2020. Accessed November 14, 2022. https:// www.who.int/publications/i/item/9789240011311
8. LeDuc JW, Anderson K, Bloom ME, et al. Framework for leadership and training of Biosafety Level 4 laboratory workers. *Emerg Infect Dis*. 2008;14(11):1685-1688.
9. Kaufman SG, Berkelman R. Biosafety "behavioral-based" training for high biocontainment laboratories: bringing theory into practice for biosafety training. *Appl Biosaf*. 2007;12(3):178-184.
10. Puro V, Fusco FM, Schilling S, et al. Biosecurity measures in 48 isolation facilities managing highly infectious diseases. *Biosecur Bioterror*. 2012;10(2):208-214.
11. Brizee S, van Passel MWJ, van den Berg LM, et al. Development of a biosecurity checklist for laboratory assessment and monitoring. *Appl Biosaf*. 2019;24(2):83-89.
12. Moritz RL, Berger KM, Owen BR, Gillum DR. Promoting biosecurity by professionalizing biosecurity. *Science*. 2020; 367(6480):856-858.
13. National Research Council. *Challenges and Opportunities for Education About Dual Use Issues in the Life Sciences*. Washington, DC: The National Academies Press; 2011. Accessed November 9, 2022. https://doi.org/10.17226/12958
14. Sta Ana JL, Frankel MS, Berger KM. Educating scientists about dual use. *Science*. 2009;326(5957):1193.

15. Salerno RM, Gaudioso J, eds. *Laboratory Biorisk Management: Biosafety and Biosecurity*. Boca Raton, FL: CRC Press; 2015.
16. Schröder I, Huang DYQ, Ellis O, Gibson J H, Wayne NL. Laboratory safety attitudes and practices: a comparison of academic, government, and industry researchers. *J Chem Health Saf*. 2016;23(1):12-23.
17. Van Noorden R. Safety survey reveals lab risks. *Nature*. 2013;493(7430):9-10.
18. Dando MR, Rappert B. *Codes of Conduct for the Life Sciences: Some Insights from UK Academia*. Briefing Paper No. 16. Bradford, UK: University of Bradford; 2005. https://core.ac.uk/reader/135056
19. Relman DA. Opinion: to stop the next pandemic, we need to unravel the origins of COVID-19. *Proc Natl Acad Sci U S A*. 2020;117(47):29246-29248.
20. Klotz L. Human error in high-biocontainment labs: a likely pandemic threat. *Bulletin of the Atomic Scientists*. February 25, 2019. Accessed November 7, 2022. https://thebulletin.org/2019/02/human-error-in-high-biocontainment-labs-a-likely-pandemic-threat/
21. Ritterson R, Kingston L, Fleming AEJ, Lauer E, Dettmann RA, Casagrande R. A call for a national agency for biorisk management. *Health Secur*. 2022;20(2):187-191.
22. Institute of Medicine and National Research Council. *Potential Risks and Benefits of Gain-of-Function Research: Summary of a Workshop*. Washington, DC: The National Academies Press; 2015. Accessed July 13, 2022. https://doi.org/10.17226/21666
23. Palmer MJ, Fukuyama F, Relman DA. A more systematic approach to biological risk. *Science*. 2015;350(6267):1471-1473.
24. Gryphon Scientific. *Risk and Benefit Analysis of Gain of Function Research: Final Report*. Takoma Park, MD: Gryphon Scientific; 2016. Accessed October 16, 2021. https://www.gryphonscientific.com/resources/gain-of-function/
25. Novossiolova TA, Whitby S, Dando M, Pearson GS. The vital importance of a web of prevention for effective biosafety and biosecurity in the twenty-first century. *One Health Outlook*. 2021;3(1):17.
26. Gronvall GK. *Synthetic Biology: Safety, Security, and Promise*. Scotts Valley, CA: CreateSpace (now Amazon Kindle Direct Publishing); 2016.
27. National Research Council. *Biotechnology Research in an Age of Terrorism*. Washington, DC: The National Academies Press; 2004. Accessed November 9, 2022. https://doi.org/10.17226/10827
28. Tucker JB, ed. *Innovation, Dual Use, and Security: Managing the Risks of Emerging Biological and Chemical Technologies*. Cambridge, MA: MIT Press; 2012.
29. Reason J, Hollnagel E, Paries J. *Revisiting the "Swiss Cheese" Model of Accidents*. Paris: EUROCONTROL; 2006. Accessed November 7, 2022. https://www.eurocontrol.int/publication/revisiting-swiss-cheese-model-accidents
30. Hale A, Borys D. Working to rule, or working safely? Part 1: A state of the art review. *Saf Sci*. 2013;55:207-221.
31. Institute of Medicine and National Research Council. *Globalization, Biosecurity, and the Future of the Life Sciences*. Washington, DC: The National Academies Press; 2006. Accessed November 9, 2022. https://doi.org/10.17226/11567
32. National Academies of Sciences, Engineering, and Medicine. *Biodefense in the Age of Synthetic Biology*. Washington, DC: The National Academies Press; 2018. Accessed November 9, 2022. https://doi.org/10.17226/24890
33. National Research Council. *Safe Science: Promoting a Culture of Safety in Academic Chemical Research*. Washington, DC: The National Academies Press; 2014. Accessed November 9, 2022. https://doi.org/10.17226/18706
34. National Science Advisory Board for Biosecurity (NSABB). *Guidance for Enhancing Personnel Reliability and Strengthening the Culture of Responsibility: A Report of the National Science Advisory Board for Biosecurity*. Washington, DC: NSABB; 2011. Accessed November 7, 2022. https://biosecuritycentral.org/resource/core-guidance-and-recommendations/personnel-reliability-and-culture-of-responsibility/
35. Trevan T. Biological research: rethink biosafety. *Nature*. 2015;527(7577):155-158.
36. Wurtz N, Papa A, Hukic M, et al. Survey of laboratory-acquired infections around the world in biosafety level 3 and 4 laboratories. *Eur J Clin Microbiol Infect Dis*. 2016; 35(8):1247-1258.
37. Perkins D, Danskin K, Rowe AE, Livinski AA. The culture of biosafety, biosecurity, and responsible conduct in the life sciences: a comprehensive literature review. *Appl Biosaf*. 2019;24(1):34-45.
38. Berkelman RL, Le Duc JW. Culture of responsibility. *Science*. 2014;345(6201):1101.
39. Weick K, Sutcliffe KM. *Managing the Unexpected: Resilient Performance in an Age of Uncertainty*. 2nd ed. San Francisco, CA: Jossey-Bass; 2007.
40. Ritterson R, Casagrande R. Basic scholarship in biosafety is critically needed to reduce risk of laboratory accidents. *mSphere*. 2017;2(2):e00010-17.
41. Evans SW, Beal J, Berger K, et al. Embrace experimentation in biosecurity governance. *Science*. 2020;368(6487):138-140.
42. National Research Council. *A Survey of Attitudes and Actions on Dual Use Research in the Life Sciences: A Collaborative Effort of the National Research Council and the American Association for the Advancement of Science*. Washington, DC: The National Academies Press; 2009. Accessed November 9, 2022. https://doi.org/10.17226/12460
43. Eccles JS, Wigfield A. Motivational beliefs, values, and goals. *Annu Rev Psychol*. 2002;53(1):109-132.
44. Wigfield A, Muenks K, Eccles JS. Achievement motivation: what we know and where we are going. *Annu Rev Dev Psychol*. 2021;3(1):87-111.
45. Abele AE, Spurk D. The longitudinal impact of self-efficacy and career goals on objective and subjective career success. *J Vocat Behav*. 2009;74(1):53-62.
46. Walton GM, Cohen GL. A brief social-belonging intervention improves academic and health outcomes of minority students. *Science*. 2011;331(6023):1447-1451.
47. Leary MR. Sociometer theory and the pursuit of relational value: getting to the root of self-esteem. *Eur Rev Soc Psychol*. 2005;16(1):75-111.
48. Sherman DK, Cohen GL. The psychology of self-defense: self-affirmation theory. *Adv Exp Soc Psychol*. 2006;38:183-242.
49. Oyserman D, Destin M. Identity-based motivation: implications for intervention. *Couns Psychol*. 2010;38(7): 1001-1043.

50. Crocker J, Canevello A, Brown AA. Social motivation: costs and benefits of selfishness and otherishness. *Annu Rev Psychol*. 2017;68:299-325.
51. Robson LS, Stephenson CM, Schulte PA, et al. A systematic review of the effectiveness of occupational health and safety training. *Scand J Work Environ Health*. 2012;38(3): 193-208.
52. Loosemore M, Malouf N. Safety training and positive safety attitude formation in the Australian construction industry. *Saf Sci*. 2019;113:233-243.
53. Zierold KM, Welsh EC, McGeeney TJ. Attitudes of teenagers towards workplace safety training. *J Community Health*. 2012;37(6):1289-1295.
54. Gibbs Jr KD, Griffin KA. What do I want to be with my PhD? The roles of personal values and structural dynamics in shaping the career interests of recent biomedical science PhD graduates. *CBE Life Sci Educ*. 2013;12(4):711-723.
55. McGee R, Keller JL. Identifying future scientists: predicting persistence into research training. *CBE Life Sci Educ*. 2007; 6(4):316-331.
56. Génova G, de la Vara JL. The problem is not professional publishing, but the publish-or-perish culture. *Sci Eng Ethics*. 2019;25(2):617-619.
57. Blackmore P, Kandiko CB. Motivation in academic life: a prestige economy. *Res Post-Compuls Educ*. 2011;16(4):399-411.
58. Bright LK. Why Do Scientists Lie? *Royal Institute of Philosophy Supplement*. 2021;89:117-129.
59. Ladd JM, Lappé MD, McCormick JB, Boyce AM, Cho MK. The "how" and "whys" of research: life scientists' views of accountability. *J Med Ethics*. 2009;35(12):762-767.
60. McCormick JB, Boyce AM, Ladd JM, Cho MK. Barriers to considering ethical and societal implications of research: perceptions of life scientists. *AJOB Prim Res*. 2012;3(3):40-50.
61. Schröder I, Czornyj E, Blayney MB, Wayne NL, Merlic CA. Proceedings of the 2018 Laboratory Safety Workshop: hazard and risk management in the laboratory. *ACS Chem Health Saf*. 2020;27(2):96-104.
62. Keiser NL, Payne SC. Are employee surveys biased? Impression management as a response bias in workplace safety constructs. *Saf Sci*. 2019;118:453-465.
63. Simmons HE, Matos B, Simpson SA. Analysis of injury data to improve safety and training. *J Chem Health Saf*. 2017;24(1):21-28.
64. Manheim DB. Results of a 2020 survey on reporting requirements and practices for biocontainment laboratory accidents. *Health Secur*. 2021;19(6):642-651.
65. Palmer MJ. Learning to deal with dual use. *Science*. 2020; 367(6482):1057.
66. Engel-Glatter S, Ienca M. Life scientists' views and perspectives on the regulation of dual-use research of concern. *Sci Public Policy*. 2018;45(1):92-102.
67. Duprex WP, Fouchier RAM, Imperiale MJ, Lipsitch M, Relman DA. Gain-of-function experiments: time for a real debate. *Nat Rev Microbiol*. 2015;13(1):58-64.
68. Noyce RS, Evans DH. Synthetic horsepox viruses and the continuing debate about dual use research. *PLoS Pathog*. 2018;14(10):e1007025.
69. Anderson MS, Martinson BC, De Vries R. Normative dissonance in science: results from a national survey of U.S. scientists. *J Empir Res Hum Res Ethics*. 2007;2(4):3-14.
70. Public Health Emergency (PHE). *United States Government Policy for Institutional Oversight of Life Sciences Dual Use Research of Concern*. Washington, DC: PHE; 2014. Accessed November 8, 2022. https://www.phe.gov/s3/dualuse/Documents/durc-policy.pdf
71. Maurer SM. *Self-Governance in Science*. Cambridge, UK: Cambridge University Press; 2017.
72. Campbell TH, Kay AC. Solution aversion: on the relation between ideology and motivated disbelief. *J Pers Soc Psychol*. 2014;107(5):809-824.
73. Chu H, Yang JZ, Liu S. Not my pandemic: solution aversion and the polarized public perception of COVID-19. *Sci Commun*. 2021;43(4):508-528.
74. Petty R, Briñol P. The elaboration likelihood model. In: Van Lange PAM, Kruglanski A, Higgins ET, eds. *Handbook of Theories of Social Psychology*. London: Sage Publications Ltd; 2012:224-245.
75. Bryson C, Hand L. The role of engagement in inspiring teaching and learning. *Innov Educ Teach Int*. 2007;44(4): 349-362.
76. University of Texas at Arlington. Biological safety. Published 2021. Accessed October 15, 2021. https://www.uta.edu/campus-ops/ehs/biological/index.php
77. Federal Bureau of Investigation. On guard against WMD: inside the Biological Countermeasures Unit, Part 1. Published February 21, 2012. Accessed January 3, 2022. https://www.fbi.gov/news/stories/on-guard-against-wmd
78. Engineering Biology Research Consortium. Malice analysis: assessing biotechnology research for security concerns. Accessed January 3, 2022. https://ebrc.org/malice-analysis/
79. Kahn LH. Can biosecurity be embedded into the culture of the life sciences? *Biosecur Bioterror*. 2012;10(2):241-246.
80. Higgins JJ, Weaver P, Fitch JP, Johnson B, Pearl RM. Implementation of a personnel reliability program as a facilitator of biosafety and biosecurity culture in BSL-3 and BSL-4 laboratories. *Biosecur Bioterror*. 2013;11(2):130-137.
81. Gaudioso J, Boggs S, Griffith NK, et al. Rethinking mitigation measures. In: Salerno RM, Gaudioso J, eds. *Laboratory Biorisk Management: Biosafety and Biosecurity*. Boca Raton, FL: CRC Press; 2015.
82. Selgelid MJ. Rappert B, ed. *Education and Ethics in the Life Sciences: Strengthening the Prohibition of Biological Weapons*. Canberra,: Australian National University Press; 2010.
83. Ménard AD, Trant JF. A review and critique of academic lab safety research. *Nat Chem*. 2020;12(1):17-25.
84. Campbell DE. *Incentives: Motivation and the Economics of Information*. Cambridge, UK: Cambridge University Press; 2006.
85. Campbell C. On the concept of motive in sociology. *Sociology*. 1996;30(1):101-114.
86. Mahal PK. Organizational culture and organizational climate as a determinant of motivation. *IUP J Manage*. 2009; 8(10):38-51.
87. Simpson EH, Balsam PD. *Behavioral Neuroscience of Motivation*. New York: Springer Publishing; 2016.
88. Emmet D. 'Motivation' in sociology and social anthropology. *J Theory Soc Behav*. 1976;6(1):85-104.
89. Social psychology. In: *Random House Unabridged Dictionary*. New York: Random House; 2022.
90. Hewstone M, Schut H, de Wit J, van den Bos K, Stroebe M, eds. *The Scope of Social Psychology: Theory and Applications*. Sussex, UK: Psychology Press; 2007.

91. Schneider FW, Gruman JA, Coutts LM. *Applied Social Psychology: Understanding and Addressing Social and Practical Problems*. Los Angeles, CA: Sage Publishing; 2005.
92. Bandura A. Social cognitive theory: an agentic perspective. *Annu Rev Psychol*. 2001;52:1-26.
93. Dweck CS. From needs to goals and representations: foundations for a unified theory of motivation, personality, and development. *Psychol Rev*. 2017;124(6):689-719.
94. Walton GM. The new science of wise psychological interventions. *Curr Dir Psychol Sci*. 2014;23(1):73-82.
95. Hale AR, Guldenmund FW, van Loenhout PLCH, Oh JIH. Evaluating safety management and culture interventions to improve safety: effective intervention strategies. *Saf Sci*. 2010;48(8):1026-1035.
96. Marigold DC, Holmes JG, Ross M. More than words: reframing compliments from romantic partners fosters security in low self-esteem individuals. *J Pers Soc Psychol*. 2007;92(2):232-248.
97. Dweck C. *Mindset: Changing the Way You Think to Fulfil Your Potential*. London: Constable & Robinson; 2017.
98. Plemmons DK, Baranski EN, Harp K, et al. A randomized trial of a lab-embedded discourse intervention to improve research ethics. *Proc Natl Acad Sci U S A*. 2020;117(3):1389-1394.
99. Association of Public Land-Grant Universities (APLU) Council on Research Task Force on Laboratory Safety. *Guide to Implementing a Safety Culture in Our Universities*. Washington, DC: APLU; 2016. Accessed November 8, 2022. https://www.aplu.org/our-work/2-fostering-research-innovation/task-force-laboratory-safety/index.html
100. Schein EH. Organizational culture. *Am Psychol*. 1990; 45(2):109-119.
101. Guldenmund FW. The nature of safety culture: a review of theory and research. *Saf Sci*. 2000;34(1-3):215-257.
102. Hofmann DA, Stetzer A. A cross-level investigation of factors influencing unsafe behaviors and accidents. *Personnel Psychol*. 1996;49(2):307-339.
103. Mearns K, Whitaker SM, Flin R. Safety climate, safety management practice and safety performance in offshore environments. *Saf Sci*. 2003;41(8):641-680.
104. Singer S, Lin S, Falwell A, Gaba D, Baker L. Relationship of safety climate and safety performance in hospitals. *Health Serv Res*. 2009;44(2 Pt 1):399-421.
105. Holland D, Shemwell SM. *Implementing a Culture of Safety: A Roadmap for Performance Based Compliance*. Bloomington, IN: Xlibris LLC; 2014.
106. Franz DR. The dual use dilemma: crying out for leadership. *St Louis U J Health Law Policy*. 2013;7(1):4.
107. Aronson E. The power of self-persuasion. *Am Psychol*. 1999;54(11):875.
108. Hulleman CS, Harackiewicz JM. Promoting interest and performance in high school science classes. *Science*. 2009; 326(5958):1410-1412.
109. Evans SW, Greene D, Hoffmann C, Lunte S. Stakeholder Engagement Workshop on the Implementation of the United States Government Policy for Institutional Oversight of Life Sciences Dual Use Research of Concern: workshop report. Preprint. *SSRN*. Posted November 2, 2021. http://dx.doi.org/10.2139/ssrn.3955051
110. Berger KM. What life scientists should know about security threats. *Science*. 2016;354(6317):1237-1239.
111. Defense Science Board (DSB). *Report of the Defense Science Board Task Force on Department of Defense Biological Safety and Security Program*. Washington, DC, DSB; 2009. Accessed October 18, 2021. https://irp.fas.org/agency/dod/dsb/biosafety.pdf
112. Trans-Federal Task Force. Report of the Trans-Federal Task Force on optimizing biosafety and biocontainment oversight. Published July 2009. Accessed November 9, 2022. https://www.ars.usda.gov/is/br/bbotaskforce/biosafety-FINAL-REPORT-092009.pdf
113. National Research Council. *Responsible Research with Biological Select Agents and Toxins*. Washington, DC: The National Academies Press; 2009. Accessed November 9, 2022. https://doi.org/10.17226/12774
114. Franz DR, LeDuc JW. Balancing our approach to the insider threat. *Biosecur Bioterror*. 2011;9(3):205-206.
115. Wilson TD. *Redirect: Changing the Stories We Live By*. Boston, MA: Little, Brown and Company; 2011.
116. Gelles MG, Brant DL, Geffert B. *Building a Secure Workforce: Guard Against Insider Threat*. Deloitte; 2012. Accessed November 9, 2022. https://blog.executivebiz.com/wp-content/uploads/Insider_Threat.pdf
117. Skvorc C, Wilson DE. Developing a behavioral health screening program for BSL-4 laboratory workers at the National Institutes of Health. *Biosecur Bioterror*. 2011;9(1):23-29.
118. Evans TM, Bira L, Gastelum JB, Weiss LT, Vanderford NL. Evidence for a mental health crisis in graduate education. *Nat Biotechnol*. 2018;36(3):282-284.
119. Eva A. How colleges today are supporting student mental health. *Greater Good*. January 11, 2019. Accessed October 16, 2021. https://greatergood.berkeley.edu/article/item/how_colleges_today_are_supporting_student_mental_health
120. Malakoff D. Hey, you've got to hide your work away. *Science*. 2013;342(6154):70-71.
121. Greenfieldboyce N. Why scientists held back details on a unique botulinum toxin. *National Public Radio*. October 9, 2013. Accessed October 16, 2021. https://www.npr.org/sections/health-shots/2013/10/11/230957188/why-scientists-held-back-details-on-a-unique-botulinum-toxin
122. Sherif M. *The Psychology of Social Norms*. New York: Harper & Brothers; 1936.
123. Cialdini RB, Trost MR. Social influence: social norms, conformity and compliance. In: Gilbert DT, Fiske ST, Lindzey G, eds. *The Handbook of Social Psychology*. Vol 2. New York: McGraw-Hill; 1998:151-192.
124. Miller DT, Prentice DA. The construction of social norms and standards. In: Higgins ET, Kruglanski AW, eds. *Social Psychology: Handbook of Basic Principles*. New York: Guilford Press; 1996:779-829.
125. Husbands JL. The challenge of framing for efforts to mitigate the risks of "dual use" research in the life sciences. *Futures*. 2018;102:104-113.
126. Bryan CJ, Walton GM, Rogers T, Dweck C. Motivating voter turnout by invoking the self. *Proc Natl Acad Sci U S A*. 2011;108(31):12653-12656.
127. Bryan CJ, Adams GS, Monin B. When cheating would make you a cheater: implicating the self prevents unethical behavior. *J Exp Psychol: Gen*. 2013;142(4):1001-1005.
128. Kuran T. *Private Truths, Public Lies*. Cambridge, MA: Harvard University Press; 1997.

129. Sargent RH, Newman LS. Pluralistic ignorance research in psychology: a scoping review of topic and method variation and directions for future research. *Rev Gen Psychol*. 2021; 25(2):163-184.
130. Merton RK. A note on science and democracy. *J Legal Pol Soc*. 1942;1(1-2):115-126.
131. Yeager DS, Hanselman P, Walton GM, et al. A national experiment reveals where a growth mindset improves achievement. *Nature*. 2019;573(7774):364-369.
132. Ben Ouaghram-Gormley S. From CRISPR babies to super soldiers: challenges and security threats posed by CRISPR. *Nonproliferation Rev*. 2020;27(4-6):367-387.
133. Bryan CJ, Tipton E, Yeager DS. Behavioural science is unlikely to change the world without a heterogeneity revolution. *Nat Hum Behav.* 2021;5(8):980-989.
134. Beer M, Eisenstat RA, Spector B. Why change programs don't produce change. *Harv Bus Rev*. 1990;68(6):158-166.
135. Karlan D, Appel J. *Failing in the Field: What We Can Learn When Field Research Goes Wrong*. New Jersey: Princeton University Press; 2018.
136. Kenthirarajah D, Walton GM. How brief social-psychological interventions can cause enduring effects. In: Scott RA, Kosslyn SM, eds. *Emerging Trends in the Social and Behavioral Sciences.* Hoboken, NJ: John Wiley & Sons; 2015.
137. Arizona State University. EHS training. Accessed January 2, 2022. https://cfo.asu.edu/ehs-training
138. Walton GM, Yeager DS. Seed and soil: psychological affordances in contexts help to explain where wise interventions succeed or fail. *Curr Dir Psychol Sci*. 2020;29(3):219-226.
139. Claro S, Paunesku D, Dweck C. Growth mindset tempers the effects of poverty on academic achievement. *Proc Natl Acad Sci U S A*. 2016;113(31):8664-8668.
140. Nosek BA, Spies JR, Motyl M. Scientific utopia: II. Restructuring incentives and practices to promote truth over publishability. *Perspect Psychol Sci*. 2012;7(6):615-631.
141. Millett P, Alexanian T. Implementing adaptive risk management for synthetic biology: lessons from iGEM's safety and security programme. *Engineering Biol*. 2021;5(3):64-71.

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