Challenges and Opportunities for Education About Dual Use Issues in the Life Sciences

ISBN
978-0-309-15840-4

146 pages
6 x 9
PAPERBACK (2010)

Committee on Education on Dual Use Issues in the Life Sciences; National Research Council

Challenges and Opportunities for Education About Dual Use Issues in the Life Sciences

Committee on Education on Dual Use Issues in the Life Sciences

Board on Life Sciences
Division on Earth and Life Studies

NATIONAL RESEARCH COUNCIL
OF THE NATIONAL ACADEMIES

In cooperation with

IAP: The Global Network of Science Academies
International Union of Biochemistry and Molecular Biology
International Union of Microbiological Societies
Polish Academy of Sciences

THE NATIONAL ACADEMIES PRESS
Washington, D.C.
www.nap.edu

THE NATIONAL ACADEMIES PRESS 500 Fifth Street, N.W. Washington, DC 20001

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This project was supported by Grant No. S-LMAQM-08-CA-1 40, A004 between the National Academy of Sciences and the Department of State. Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the views of the organizations or agencies that provided support for the project.

International Standard Book Number-13: 978-0-309-15840-4
International Standard Book Number-10: 0-309-15840-0

Additional copies of this report are available from the National Academies Press, 500 Fifth Street, N.W., Lockbox 285, Washington, D.C. 20055; (800) 624-6242 or (202) 334-3313 (in the Washington metropolitan area); Internet, http://www.nap.edu.

Printed in the United States of America

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Acknowledgments

This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the National Academies' Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the process.

We wish to thank the following individuals for their review of this report:

Spencer Benson, *University of Maryland*
Marie Chevrier, *University of Texas, Dallas*
Malcolm Dando, *University of Bradford, United Kingdom*
Michael Hanna, *University of Michigan*
Elizabeth Heitman, *Vanderbilt University Medical Center*
Joseph Kanabrocki, University of Chicago
Francis L. Macrina, *Virginia Commonwealth University*
Henry Metzger, *National Institutes of Health*
Jonathan Tucker, *James Martin Center for Nonproliferation Studies, Monterey Institute of International Studies*
Richard Witter, *U.S. Department of Agriculture*

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations, nor did they see the final draft of the report before its release. The review of this report was overseen by **W. Emmett Barkley,** *Proven Practices, LLC*. Appointed by the National Academies, he was responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the institution.

The Polish Academy of Sciences served as the host for the workshop in November 2009. In addition to the able leadership of Professor Andrzej Górski, vice president of the Polish Academy, Dr. Urszula Wajcen, Director of International Relations, and two members of her staff, Anna Sienkiewicz and Joanna Szwedowska-Kotlinska, ensured the smooth and successful operation of the workshop.

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Summary

BACKGROUND

A workshop at the Polish Academy of Sciences in November 2009 was the latest in a series of activities organized by national and international scientific organizations to address concerns that continuing advances in the life sciences, while offering great current and potential benefits, could also yield knowledge, tools, and techniques that could be misused for biological weapons or for bioterrorism. This workshop addressed the question of how education about these "dual use" issues might form part of a much broader response to the security risks that would also enable scientific progress to continue and its benefits to be available to all.

The workshop was the result of a request by the U.S. Department of State to the IAP, the Global Network of Science Academies. Funding was provided through the Department's Biosecurity Engagement Program, which is committed to developing cooperative international programs that promote the safe, secure and responsible use of biological materials that are at risk of accidental release or intentional misuse. The IAP also provided funding for travel by participants from developing countries.

The IAP carries out its work through groups of member academies; in this case, its Biosecurity Working Group, which was created in 2004 and includes the academies of China, Cuba, the Netherlands (chair), Nigeria, the United Kingdom and the United States. The Polish Academy of Sciences served as the host for the workshop,[1] and the National Research

[1] The Polish Academy became a member and chair of the Working Group in early 2010.

Council (NRC) of the U.S. National Academy of Sciences took responsibility for preparing the report. The two academies and IAP shared the organizing and arrangements, and were joined by two international scientific unions—the International Union of Biochemistry and Molecular Biology and the International Union of Microbiological Societies—as partners in the project.

The NRC followed its normal practices and appointed an ad hoc committee with a majority of international members to help organize the workshop with the partner organizations and to be responsible for the report. The complete statement of task for the project may be found in Box S-1; its basic goals were to:

- survey strategies and resources available internationally for education on dual use issues and identify gaps;
- consider ideas for filling the gaps, including development of new educational materials and implementation of effective teaching methods; and
- discuss approaches for including education on dual use issues in the training of life scientists.

The two-and-a-half day workshop combined plenary sessions and small

BOX S-1
Statement of Task

Considerable work has been done in the past few years by the [U.S. National] Academies and other international organizations on dual use research in the life sciences, and particularly the need to educate the science community more effectively about the challenges and risks. Building on that body of work, at the request of the State Department, an ad hoc committee will develop recommendations for the most effective education internationally of life scientists on dual use issues. To inform its work the committee will convene a workshop to:

- survey strategies and resources available internationally for education on dual use issues and identify gaps,
- consider ideas for filling the gaps, including development of new educational materials and implementation of effective teaching methods, and
- discuss approaches for including education on dual use issues in the training of life scientists.

Based on the workshop and additional data gathering, the committee will produce a consensus report, which will make recommendations on the topics addressed in the workshop.

group discussions; two papers commissioned for the meeting and additional reports and studies provided further background. More than sixty participants from almost thirty countries took part and included practicing life scientists, bioethics and biosecurity practitioners, and experts in the design of educational programs. The participants' backgrounds and experience reflected two basic themes for the workshop:

- To engage the life sciences community, the particular security issues related to research with dual use potential would best be approached in the context of responsible conduct of research, the wider array of issues that the community addresses to fulfill its responsibilities to society.
- Education about dual use issues would benefit from the insights of the "science of learning," the growing body of research about how individuals learn at various stages of their lives and careers and the most effective methods for teaching them, which provides the foundation for efforts in many parts of the world to improve the teaching of science and technology at all levels of instruction.

The workshop and the committee's report are intended to inform a number of audiences, including decision-makers at the national and international level and the community of experts about dual use issues and biosecurity in many sectors. One important audience is those carrying out education in the life sciences in colleges and universities, with an emphasis on graduate students and postdoctoral fellows. The findings and recommendations are also relevant for those charged with the education of technical and professional staff in settings such as research institutes or other laboratories, although they do not receive as much attention in the report. The report does not address education about dual use issues for students at the secondary level, although the resources and methods discussed may be relevant and the increasing availability of equipment and techniques to ever-younger students suggests that this is an audience to be considered in future efforts. One of the special features of the workshop was the inclusion of experts in the research about teaching and learning and the report contains a chapter that provides a brief primer on the insights from the research that can inform education about dual use issues.

The Current State of Education About Dual Use Issues

The committee sought to identify a baseline about (1) the extent to which dual use issues are currently being included in postsecondary education (undergraduate and postgraduate) in the life sciences; (2) in what contexts that education is occurring (e.g., in formal coursework, informal settings, as stand-alone subjects or part of more general training, and in what fields); and (3) what online educational materials addressing research in the life sciences with dual use potential already exist. Based on the commissioned papers, other background materials, and the discussions at the workshop, the committee arrived at several findings.

- **Available evidence suggests that, to date, there has been very limited introduction of education about dual use issues, either as stand-alone courses or as parts of other courses. Furthermore, few of the established courses appear to incorporate the best practices and lessons learned from research on the "science of learning."**
- **Because a significant amount of information and training about responsible conduct and biosafety is provided informally, either through dedicated modules outside regular coursework or in-laboratory mentoring by senior researchers, currently available evidence may understate the amount of education on these general issues that is actually available to students. It remains unclear whether discussions of dual use may be more widespread than the background surveys indicated.**
- **A number of online resources for education about dual use issues are available, both for use by individuals and as the basis for or as supplements to courses. Only a few of the resources are explicitly designed to support active and engaged learning.**

The committee also identified two other findings that add further context to an understanding of the current conditions.

- **There is some evidence of an increase in the introduction of dual use issues into education in the life sciences. These examples come from all over the world and seem to result primarily from the work of an interested, committed individual or a specific project, often by a nongovernmental organization.**
- **At present, most of the examples of education about dual use issues occur as part of more general education about responsible conduct of research, in basic life sciences courses, as part of biosafety training, or within bioethics. In the United States, this extends to the specific education on responsible conduct of research (RCR) and research ethics that is mandated by the National Institutes of Health and the National Science Foundation.**

GAPS, NEEDS, AND POTENTIAL REMEDIES

The remainder of the committee's charge was to identify gaps and needs based on its review of currently available courses and materials and suggest ways in which those gaps might be filled and the needs met. The committee divided its task among three broad headings, each of which includes conclusions about the gaps and needs that exist and some of the promising ways in which these might be addressed.

Educational Materials and Methods

The discussions during the workshop made clear that, beyond the available online resources, additional educational materials and resources are needed if discussions of research with dual use potential are to be incorporated more widely and effectively into education programs for life scientists around the world. Participants at the workshop addressed questions on the suggested content of these materials, the types of teaching methods that would be effective in presenting them, and the opportunities for developing materials more collaboratively and disseminating them more widely. One of the recurring themes in the discussion was that "no one size fits all," given the diversity of fields, interests, and experiences across the life sciences. The key is making the issue relevant to students and this requires a tailored approach. At the same time, participants also stressed the importance of finding ways to share successful practices and lessons learned as the scope and scale of education about dual use issues expands. The committee's conclusions with regard to these issues are:

- **Additional materials are needed that will be relevant to diverse audiences in many parts of the world, as well as those at different educational stages, in different fields within the life sciences, and in related research communities. A number of good resources have been developed, but there is a need for more that are relevant to research related, for example, to plants or animals and to fields that are not as obviously security-related.**
- **More materials are needed in languages other than English. This will be particularly important in undergraduate settings or when used as part of technical training (i.e., biosafety).**
- **In addition to online resources, materials such as CDs or DVDs that can provide comparable opportunities for engaged learning are needed for areas that lack the sustained access or capacity to take full advantage of web-based materials.**
- **Providing widespread access to materials that could be adapted for specific contexts or applications through open access reposi-**

tories or resource centers would be important to implementing and sustaining education about dual use issues.

- **Given current technology, it would be feasible to create the capacity to develop materials through online collaborations, as part of or in partnership with repositories or resource centers. Online collaborative tools can be a key mechanism to facilitate global participation in the development of materials, although again issues of access to the Internet will need to be considered in designing any arrangements.**
- **Developing methods and capacity for the life sciences and educational communities to comment on and vet education materials, such as an appropriately monitored Wikipedia model, would be important. Another important capacity would be the ability to share lessons learned and best practices about materials and teaching strategies as experience with education about dual use issues expands. If appropriate resources are available, both this and the previous conclusion should be well within the capacity of current online technologies.**
- **Teaching strategies need to focus on active learning and clear learning objectives, while allowing for local adaptation and application.**

Implementing Education About Dual Use Issues: Practical Considerations

A recurring theme during the workshop was the variety of settings in which content about dual use issues could be introduced. This reflected the diversity of the participants and the conditions in which education about dual use issues is currently taking place. It also led to discussions of a range of needs and challenges that are reflected in the committee's conclusions.

- **Incorporating education about dual use issues into the channels through which life scientists already receive their exposure to issues of responsible conduct—biosafety, bioethics and research ethics, and RCR—offers the greatest opportunity to reach the largest and most diverse range of students and professionals. Biosafety training reaches those with the most capabilities, knowledge, and motivation relevant to dual use. In addition, biosafety may be of particular interest for developing countries that are attempting to raise their overall standards of laboratory practices. Ethics and RCR are more general and may reach more**

people. The available evidence suggests that the use of multiple channels is already the most common approach.

- **If the approach above is taken, then growing interest in expanding education about dual use issues, such as a proposal under consideration with the U.S. government to require such education for all federally funded life scientists, might also be an opportunity to expand more general education about responsible conduct.**
- **It will be important to reach out to other disciplines that are increasingly part of life sciences research—physical sciences, mathematics, and engineering—as part of education about dual use issues. There may also be useful ideas and lessons from how these fields provide education about ethical issues and the potential for misuse of scientific results.**
- **Training opportunities to help faculty develop the skills, abilities and knowledge needed to teach dual use issues effectively are essential if education about dual use issues is to expand successfully.**
- **There are several promising models for "train-the-trainer" programs on which to draw, but a common characteristic is the use of the experience to create a network among faculty to support and sustain each other and to encourage expanded education.**
- **It is important to consider appropriate approaches to assessment and evaluation of education about dual use issues early in the process of developing and implementing new courses and modules.**
- **In addition to a lack of awareness of and engagement in dual use issues among life scientists, there are a number of obstacles to any effort to implement new content or teaching methods, such as competition for space in crowded curricula, pressures on students to focus on their research, and in some cases a general lack of support for teaching.**

Broader Implementation Issues

Questions related to education about dual use issues can be considered part of the larger discussions and activities that have been taking place in the international scientific community about biosecurity. For example, an examination of the roles of academies, scientific unions, and professional associations, or the roles of governments and international organizations cuts across many specific issues. The workshop and the committee also considered the perennial question of resources, both what is needed and how some of these organizations could contribute.

- **Scientific organizations as well as professional associations are playing leading roles in developing international support for education about dual use issues. There are significant opportunities to build on this work to carry out more systematic and coordinated efforts.**
- **To enable dual use issues to become a regular part of the curriculum across the life sciences, significant sustained funding will be required to fill the gaps, such as the need for new materials in multiple languages, identified in the workshop and other reports.**
- **Private sources such as foundations have played and can continue to play an important role in supporting the development and implementation of education about dual use issues. Beyond any private resources, the sustained support of governments will be necessary.**
- **Governments can also play a number of other roles besides providing funds to encourage the expansion of education about dual use issues.**
- **Two international organizations have particularly important roles in encouraging education about dual use issues. The World Health Organization has a particular role in biosafety, while the United Nations Educational, Scientific, and Cultural Organization could make significant contributions through its work in bioethics and general science ethics. In addition, the upcoming Seventh Review Conference of the Biological and Toxin Weapons Convention in 2011 will provide an obvious opportunity for member states to build on prior work and take affirmative steps in support of education about dual use issues.**

THE COMMITTEE'S RECOMMENDATIONS

Although its findings led to conclusions, not all of the conclusions led to recommendations because the committee wanted to focus attention on those it felt were the most important to achieving the larger goal.

General Approach

An introduction to dual use issues should be part of the education of every life scientist.

- **Except in specialized cases (particular research or policy interests), this education should be incorporated within broader coursework and training rather than via stand-alone courses.**

Appropriate channels include biosafety, bioethics and research ethics, and professional standards (i.e., RCR), as well as inclusion of examples of research with dual use potential in general life sciences courses.

- **Insights from research on learning and effective teaching should inform development of materials, and approaches to teaching students and preparing faculty.**

Specific Actions

Achieving the broad goal of making dual use issues part of broader education will require a number of specific actions. They may be undertaken separately by different organizations but there will be substantial benefit if there is an effort to coordinate across the initiatives and share successful practices and lessons learned. Resources will be needed to ensure that the initiatives are carried out at an appropriate scale and scope.

The workshop participants and the committee did not explore the implementation of any specific recommendations in sufficient depth to prescribe a particular mechanism or path forward. Instead, reflecting the diversity and variety of situations in which education about dual use issues will be carried out, the final chapter lays out a number of options that could be used to implement each of the recommendations below.

- **Develop an international open access repository of materials that can be tailored to and adapted for the local context, perhaps as a network of national or regional repositories.**
  - **—The repository should be under the auspices of the scientific community rather than governments, although support and resources from governments will be needed to implement the education locally.**
  - **—Materials should be available in a range of languages.**
  - **—Materials should interface with existing databases and repositories of educational materials dedicated to science education.**
  - **—Additional case studies to address broader segments of the life sciences community should be developed, with a focus on making the case studies relevant to the student/researcher.**
- **Design methods for commenting and vetting of materials by the community (such as an appropriately monitored Wikipedia model) so they can be improved by faculty, instructors and experts in science education.**
- **Build networks of faculty and instructors through train-the-trainer programs, undertaking this effort if possible in coop-**

eration with scientific unions and professional societies and associations.

- **Develop a range of methods to assess outcomes and, where possible, impact. These should include qualitative approaches as well as quantitative measures, for example, of learning outcomes.**

1

Introduction

BACKGROUND

In mid-November 2009, more than sixty people from almost thirty countries gathered at the Polish Academy of Sciences in Warsaw for a workshop devoted to expanding education about so-called "dual use" research among the life sciences community. (As used here and throughout this report, the term refers to the possible beneficial or malevolent use of reagents, organisms, technologies, or information.) The workshop resulted from a request by the U.S. Department of State to the IAP, the Global Network of Science Academies, which is committed to making the voice of science heard on issues of crucial importance to the future of humankind.[1] The State Department provided funding through its Biosecurity Engagement Program, which is committed to developing cooperative international programs that promote the safe, secure and responsible use of biological materials that are at risk of accidental release or intentional misuse. The IAP also provided funding to support travel by participants from developing counties.

The IAP carries out its work through groups of member academies; in this case its Biosecurity Working Group, which was created in 2004

[1] The IAP, formerly known as the InterAcademy Panel on International Issues, currently has a membership of 106 scientific academies from around the world; these include both national academies/institutions as well as regional/global groupings of scientists. A number of other scientific organizations participate in IAP meetings and activities as observers. Additional information may be found at http://www.interacademies.net/.

and includes the academies of China, Cuba, the Netherlands (chair through 2009), Nigeria, the United Kingdom and the United States. The Polish Academy of Sciences served as the host for the workshop,[2] and the National Research Council (NRC) of the U.S. National Academy of Sciences took responsibility for preparing the report. The two academies and IAP shared the organizing and arrangements, and were joined by two international scientific unions—the International Union of Biochemistry and Molecular Biology and the International Union of Microbiological Societies—as partners in the project.

The NRC followed its normal practices and appointed an ad hoc committee to help organize the workshop with the partner organizations and be responsible for the report. In keeping with the international nature of the project, a majority of the committee members were non-U.S. citizens; brief biographical sketches may be found in Appendix A. The specific task given to the committee was to:

> develop recommendations for the most effective education internationally of life scientists on dual use issues. To inform its work the committee will convene a workshop to:
>
> - survey strategies and resources available internationally for education on dual use issues and identify gaps,
> - consider ideas for filling the gaps, including development of new educational materials and implementation of effective teaching methods, and
> - discuss approaches for including education on dual use issues in the training of life scientists.
>
> Based on the workshop and additional data gathering, the committee will produce a consensus report, which will make recommendations on the topics addressed in the workshop.

The two-and-a-half-day meeting combined plenary sessions with smaller working group discussions to facilitate the exchange of information and the development of ideas to support increased implementation of education on dual use issues. The agenda and participants list for the workshop may be found in Appendix B. The workshop sought to take advantage of the substantial amount of work that had already been done to prepare the ground for implementing significant new educational efforts. Workshop participants included practicing life scientists, bioethics and biosecurity practitioners, and experts in the design of educational programs, reflecting two basic themes for the workshop:

[2] The Polish Academy became a member and chair of the Working Group in early 2010.

- To engage the life sciences community, the particular security issues related to dual use research would best be approached in the context of responsible conduct of research, the wider array of issues that the community addresses in its efforts to fulfill its responsibilities to society.
- Education about dual use issues would benefit from the insights of the "science of learning," the growing body of research about how individuals learn at various stages of their lives and careers and the most effective methods for teaching them, which provides the foundation for efforts in many parts of the world to improve the teaching of science and technology at all levels of instruction.

This chapter and Chapter 2 explain and develop these two themes in more detail, with Chapter 2 providing a primer on the results of research about learning and effective approaches to teaching. They are followed by two chapters devoted to the specific issues addressed during the workshop and the committee's findings, conclusions, and recommendations about them.

The workshop and the committee's report are intended to inform a number of audiences, including decision-makers at the national and international level and the community of experts about dual use issues and biosecurity in many sectors. One important audience is those carrying out education in the life sciences in colleges and universities, with an emphasis on graduate students and postdoctoral fellows. The findings and recommendations are also relevant for those charged with the education of technical and professional staff in settings such as research institutes or other laboratories, although they do not receive as much attention in the report. The report does not address education about dual use issues for students at the secondary level, although the resources and methods discussed may be relevant and the increasing availability of equipment and techniques to ever-younger students suggests that this is an audience to be considered in future efforts.

THE BROAD CONTEXT OF SCIENCE AND SOCIETY

Science is not conducted in a social vacuum; as the most recent edition of *On Being a Scientist*, the widely used introduction to responsible conduct of research from the National Academies notes:

> The standards of science extend beyond responsibilities that are internal to the scientific community. Researchers also have a responsibility to reflect on how their work and the knowledge they are generating might be used in the broader society. (NRC 2009a:48)

The second edition of the guide had already made clear that these obligations extended across the scientific community:

> Even scientists conducting the most fundamental research need to be aware that their work can ultimately have a great impact on society. Construction of the atomic bomb and the development of recombinant DNA—events that grew out of basic research on the nucleus of the atom and investigations of certain bacterial enzymes, respectively—are two examples of how seemingly arcane areas of science can have tremendous societal consequences. The occurrence and consequences of discoveries in basic research are virtually impossible to foresee. Nevertheless, the scientific community must recognize the potential for such discoveries and be prepared to address the questions that they raise. If scientists do find that their discoveries have implications for some important aspect of public affairs, they have a responsibility to call attention to the public issues involved. . . . science and technology have become such integral parts of society that scientists can no longer isolate themselves from societal concerns. (NRC 1995:20-21)

The conduct of science itself may also be shaped by changing social attitudes. A clear example is the development of standards for the treatment of human subjects in experiments, which developed over time, particularly during the twentieth century in response to what were judged to be egregious abuses by researchers (IOM 2001). The standards for the treatment of laboratory animals have continued to evolve as well (NRC 2010). More generally, the ability to conduct science depends on public trust and support, not least because a substantial portion of research funding comes from governments. The loss of public trust in particular areas of science could mean that research could not proceed or that its results would be the subject of controversy. Ultimately, this could prevent science from serving one of its key social functions—informing policy decisions with important scientific or technical components.

Most contemporary articulations of the social responsibilities of scientists focus on the most general duties and obligations of scientists and researchers. At this level of granularity, obligations must be interpreted and contextualized. That is, norms and general sentiments (e.g., Do No Harm), do not provide guidance to individuals about specific situations. Furthermore, any given norm or general obligation allows for innumerable unique interpretations. This most general level of obligation can answer only those questions about science's responsibility to society that are solely ethical, rather than legal or professional. Such norms do not translate into a single set of specific or explicit actions for those engaged in the scientific enterprise. This has the drawback of being ostensibly unenforceable or not codifiable into anything but tenets, but constructing an ethical framework with any greater degree of specificity is problematic. Even if we believed that a system encompassing all possible ethical problems in the life sciences could be conceived or developed, such a framework would be untenably inflexible (i.e., it could not grow as the life sciences develop). Perhaps more importantly, while specific obligations may be too grounded in a distinct sociohistorical setting to be useful outside of that particular context,[3] meaningful responses to concerns about the responsibility of science to society are best articulated as general and universalizable norms and obligations.

That these issues are both ethical and best framed in abstract or general ways has a significant impact on the way education in social responsibility of science is conducted. Any training or education that arises out of this theoretical groundwork, because of its contingency, also needs to focus on the general and abstract moral duties in play, rather than context-specific obligations. This may be reflected in the distinctions among various kinds of codes to govern scientific conduct.[4]

> ***Aspirational codes*** (often designated as 'codes of ethics') set out ideals that practitioners should uphold, such as standards of research integrity, honesty, or objectivity. . . .
>
> ***Educational/Advisory codes*** (often designated as 'codes of conduct') would go further than merely setting aspirations by providing guidelines suggesting how to act appropriately. . . .
>
> ***Enforceable codes*** (often designated as 'codes of practice') seek to further codify what is regarded as acceptable behavior. Rather than inspiring or educating in the hopes of securing certain outcomes, enforceable codes are embedded within wider systems of professional or legal regulation. (Rappert 2004:14-17)

Another response to the question of providing practical guidance to scientists about appropriate conduct that could go beyond generalizations is the widespread use of case studies or scenarios, to encourage students to work through the ethical issues and develop their own views about appropriate responses. NRC's *On Being a Scientist* (2009a), for example, contains short case studies to illustrate each of the basic ethical issues it addresses.

The fundamental question in developing standards for responsible conduct of research may be one of degree: whether the social responsibility

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[3] For a brief but insightful discussion of internalized and externalized obligations see Kuhlau et al. (2008:480).

[4] Proponents of codes of conduct do not argue that they will prevent an individual determined to do harm from carrying out his or her intentions. Rather codes serve as evidence of the commitment of individuals and organizations to use the results of science only for beneficial purposes and as educational tools to foster a broader culture of responsibility.

of science is negative (e.g., the Hippocratic "Do No Harm" or Google's "Don't Be Evil") or positive (i.e., scientists have an obligation or duty to work to promote public welfare, such as the UK Government Office for Science's *Rigour, Respect, and Responsibility: A Universal Ethical Code for Scientists* [2007]). Responses to this question of degree vary among institutions, but policy and scientific communities have worked to generate and expand current guidelines and codes of conduct. The attention devoted to social responsibility by scientific societies, advocacy groups, and academic communities has helped to establish conventions and norms, as well as a theoretical grounding for training and education in these areas. A number of high-level declarations and statements in recent years have reinforced the ethical imperatives involved in scientific research across the global scientific community. For example, the 1999 World Conference on Science, a collaboration of the International Council for Science (ICSU) and the UN Educational, Scientific, and Cultural Organization (UNESCO), produced the Declaration on Science and the Use of Scientific Knowledge, which proclaimed that:

> The practice of scientific research and the use of knowledge from that research should always aim at the welfare of humankind, including the reduction of poverty, be respectful of the dignity and rights of human beings, and of the global environment, and take fully into account our responsibility towards present and future generations,

and further that

> All scientists should commit themselves to high ethical standards, and a code of ethics based on relevant norms enshrined in international human rights instruments should be established for scientific professions. The social responsibility of scientists requires that they maintain high standards of scientific integrity and quality control, share their knowledge, communicate with the public and educate the younger generation. Political authorities should respect such action by scientists. Science curricula should include science ethics, as well as training in the history and philosophy of science and its cultural impact. (UNESCO 1999)[5]

In 2006, ICSU disbanded its Standing Committee on Freedom in the Conduct of Science and replaced it with a new standing Committee on Freedom *and Responsibility* in the Conduct of Science (emphasis added).

[5] Key documents from the World Conference on Science are available at http://www.unesco.org/science/wcs/, including the text of the Declaration on Science and the Use of Scientific Knowledge in six languages, http://www.unesco.org/science/wcs/eng/declaration_e.htm.

Without in any way diminishing its commitment to the principles of the universality of science, such as the rights of scientists to travel, associate, and communicate freely, the new committee "differs significantly from its predecessors in that it has been explicitly charged with also considering the responsibilities of scientists" (ICSU 2008:2).[6]

THE LIFE SCIENCES AND DUAL USE ISSUES

Continuing advances in the life sciences over the last 50 years, supported by new enabling technologies, have brought great benefits for health, the economy, and the environment. Many believe that the life sciences hold far greater promise for the future.

> Biology is at a point of inflection. Years of research have generated detailed information about the components of the complex systems that characterize life—genes, cells, organisms, ecosystems—and this knowledge has begun to fuse into greater understanding of how all those components work together as systems. Powerful tools are allowing biologists to probe complex systems in ever-greater detail, from molecular events in individual cells to global biogeochemical cycles. Integration within biology and increasingly fruitful collaboration with physical, earth, and computational scientists, mathematicians, and engineers are making it possible to predict and control the activities of biological systems in ever greater detail. . . . [T]he life sciences have reached a point where a new level of inquiry is possible, a level that builds on the strengths of the traditional research establishment but provides a framework to draw on those strengths and focus them on large questions whose answers would provide many practical benefits. (NRC 2009b:12-13)

A wide range of national governments and regional and international organizations are creating visions and implementing strategies to apply these advances to the needs and ambitions of the developed and developing world (e.g., OECD 2009; African Union 2006).

Along with the achievements and hopes, however, have come a range of concerns about the implications and impacts of current and potential advances. These range from a fundamental unease about how the increasing knowledge of basic life processes will be applied to specific concerns about unintended effects on health or the environment (NRC 2002, 2005a, 2009c; IOM 2010). Among these specific concerns is the potential security risk that states or terrorist groups or even individuals could misuse the knowledge, tools and techniques gained through life sciences research for

[6] The ICSU statement on the universality of science may be found at http://www.icsu.org/5_abouticsu/INTRO_UnivSci_1.html.

biological weapons or bioterrorism. In May 2000, Matthew Meselson, a leading figure in the life sciences on issues related to biological weapons, offered a warning at the annual meeting of the U.S. National Academy of Sciences:

> Every major technology—metallurgy, explosives, internal combustion, aviation, electronics, nuclear energy—has been intensively exploited, not only for peaceful purposes but also for hostile ones. Must this also happen with biotechnology, certain to be a dominant technology of the coming century? During the century just begun, as our ability to modify fundamental life processes continues its rapid advance, we will be able not only to devise additional ways to destroy life but will also be able to manipulate it—including the processes of cognition, development, reproduction, and inheritance. A world in which these capabilities are widely employed for hostile purposes would be a world in which the very nature of conflict has radically changed. Therein could lie unprecedented opportunities for violence, coercion, repression, or subjugation. (Meselson 2000)

Concerns about the potential security risks posed by life sciences research can be seen in the context of rising concerns—and sometimes sharp disagreements—about the more general risks of weapons of mass destruction (WMD), including biological weapons and bioterrorism, following the end of the Cold War (see, for example, Carter, Deutch, and Zelikov 1998). More specifically, a number of articles in scientific journals early in this decade sparked controversy about whether the risks cited by Meselson were already present, with critics charging that the publications could provide a "blueprint" or "roadmap" for nations or terrorists.[7] Yet even work with the greatest seeming potential for misuse most often also offers significant potential benefits, and judgments about the implications of research were seldom simple or definitive. Box 1-1 contains examples of some of the contentious articles; in every case the reality and extent of the risk were vigorously debated.

The possibilities—and attendant uncertainties—regarding whether and how advances in the life sciences intended for legitimate and beneficent purposes might also be used for malevolent ends has come to be called the "dual use dilemma" (NRC 2004a:1), a term that is the subject of considerable debate. For the purposes of the workshop, Professor Michael Imperiale, a member of the NRC organizing committee and the U.S.

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[7] A review of some of the best known articles from that period may be found in *Biotechnology Research in an Age of Terrorism* (NRC 2004a:25-29), while a review of the issues and policy options then under discussion may be found in Epstein (2001). An example of the concern in the defense policy community is Zilinskas and Tucker (2002).

BOX 1-1
Examples of Research with Dual Use Potential

The debates sparked by the publication of data related to the reconstruction of the 1918 influenza virus[1] illustrated how scientific achievements may also generate security concerns. The additional recent research endeavors listed below were all identified as having the potential for misuse. In all cases, there was debate and discussion within the scientific community and between the scientific and security communities about whether these cases indeed presented security risks.

- ***Synthesis of infectious poliovirus.***[2] Researchers sought to resolve the unusual nature of poliovirus, which behaves as both a chemical and a "living" entity. They succeeded in recreating the virus by chemically synthesizing a cDNA of its genome. Some critics assert that the publication of their methods provided a recipe for terrorists by showing how one could create any virus from chemical reagents purchasable on the open market. The researchers acknowledged this potential but noted that a threat of bioterrorism arises only if mass vaccinations against polio end.
- ***Development of "stealth" viruses that could evade the human immune system.***[3] These viruses are being developed to serve as molecular means for introducing curative genes into patients with inherited diseases. However, the research has raised questions about whether they could potentially be induced to express dangerous proteins, such as toxins.
- ***A method for the construction of "fusion toxins" derived from two distinct nontoxic chemical predecessors.***[4] This technique was originally investigated for the purpose of killing cancer cells, but some argue that it might be redirected to develop novel toxins that could target the normal cells of almost any tissue when introduced into a human host.
- ***Genetic engineering of the tobacco plant to produce subunits of cholera toxin.*** Because tobacco is easy to engineer, it is a likely candidate for producing plant-based vaccines. The technique could be used to produce large quantities of cholera toxin cheaply and relatively easily, paving the way for fast and efficient vaccine production. Concerns have arisen that it might also have a potential for misuse.[5]
- ***Development of new technologies for delivering drugs by aerosol spray in individual doses.*** Some have expressed concern that this development, intended to improve the ease of use and rate of compliance among diabetic users of insulin, could be adapted to allow aerosol sprays to cover wider areas in an attack.[6]

Nonlaboratory research may also lend itself to possible misuse. Investigation of the potential effects of a deliberate release of botulinum toxin into the U.S. milk supply recommended aggressive pursuit of early detection measures and new research on means to inactivate the toxin. Publication of the studies pinpointed weaknesses in the system that critics argue could help direct a terrorist to the most vulnerable points in the milk supply.[7]

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[1] Gibbs, M. J., J. S. Armstrong, and A. J. Gibbs. 2001. Recombination in the hemagglutinin gene of the 1918 "Spanish flu." *Science* 293(5536):1842-1845.

continued

BOX 1-1 Continued

[2] Cello, J., A. V. Paul, and E. Wimmer. 2002. Chemical synthesis of poliovirus cDNA: generation of infectious virus in the absence of natural template. *Science* 297(5583):1016-1018.
[3] Aldous, P. 2001. Biologists urged to address risk of data aiding bioweapon design. *Nature* 414(6861):237-238 as cited in R. A. Zilinskas and J. B. Tucker (2002), Limiting the contribution of the open scientific literature to the biological weapons threat. *Journal of Homeland Security*. Available online at www.homelandsecurity.org/journal/Articles/tucker.html.
[4] Arora, N., and S. H. Leppa. 1994. Fusions of anthrax toxin lethal factor with Shiga toxin and diphtheria toxin enzymatic domains are toxic to mammalian cells. *Infection and Immunity* 62(11):4955-4961.
[5] Wang, X. G., G. H. Zhang, C. X. Liu, Y. H. Zhang, C. Z. Xiao, and R. X. Fang. 2001. Purified cholera toxin b subunit from transgenic tobacco plants possesses authentic antigenicity. *Biotechnology and Bioengineering* 72(4):490-494.
[6] Boyce, N. 2002. Should scientists publish work that could be misused? *US News and World Report* 132(22):60.
[7] Wein, L. M., and Y. Liu. 2005. Analyzing a bioterror attack on the food supply: The case of botulinum toxin in milk. *Proceedings of the National Academy of Sciences USA* 102(28):9984-9989.

National Science Advisory Board for Biosecurity (NSABB) (see below), presented and discussed definitions of several key concepts as an aid to common understandings during the first plenary session.[8]

Dual Use Research: In the life sciences, dual use refers to the possible beneficial or malevolent use of reagents, organisms, technologies, or information.

[8] The term "biosecurity" illustrates some of the difficulties, for example. At its most basic, the term in some languages does not exist or is identical with "biosafety"; French, German, Russian, and Chinese are all examples of this immediate practical problem. Even more serious, the term is already used to refer to several other major international issues. For example, to many "biosecurity" refers to the obligations undertaken by states adhering to the Convention on Biodiversity and particularly the Cartagena Protocol on Biosafety, which is intended to protect biological diversity from the potential risks posed by living modified organisms resulting from modern biotechnology. (Further information on the convention may be found at http://www.cbd.int/convention/ and on the Protocol at http://www.cbd.int/biosafety/). "Biosecurity" has also been narrowly applied to efforts to increase the security of dangerous pathogens, either in the laboratory or in dedicated collections; guidelines from both the World Health Organization (WHO 2004) and the Organization for Economic Cooperation and Development (OECD 2007) use this more restricted meaning of the term. In an agricultural context, the term refers to efforts to exclude the introduction of plant or animal pathogens. (See Rusek 2009 for a discussion of this and other issues related to terminology.) Earlier NRC reports (2004a,b, 2006, 2009d,e,f) confine the use of "biosecurity" to policies and practices to reduce the risk that the knowledge, tools, and techniques resulting from research would be used for malevolent purposes. This report uses the term to cover security for both pathogens and for the information that results from research.

Dual Use Research of Concern: Dual use research of concern refers to a subset of dual use research that poses the greatest risk of harm. "Research that, based on current understanding, can be reasonably anticipated to provide knowledge, products, or technologies that could be directly misapplied by others to pose a threat to public health and safety, agricultural crops and other plants, animals, the environment, or materiel" (National Science Advisory Board for Biosecurity [NSABB] 2007:17).

Biosafety: "Laboratory biosafety describes the containment principles, technologies and practices that are implemented to prevent the unintentional exposure to pathogens and toxins, or their accidental release (World Health Organization" [WHO] 2006:iii).

Biosecurity: "The objective of biosecurity is to prevent loss, theft or misuse of microorganisms, biological materials, and research-related information" (Centers for Disease Control and Prevention [CDC] and U.S. National Institutes of Health [NIH] 2007:105).

Prof. Imperiale acknowledged, however, that some level of confusion and debate was probably unavoidable and that the best approach would be to present the terms in as unambiguous a manner as possible with an explanation in the context in which they are being used.

The types of life sciences research potentially affected by the dual use dilemma are much broader than the infectious disease agents that have been the traditional focus of biological weapons research programs (Wheelis, Rózsa, and Dando 2006).

> [L]ife sciences research is being pursued for a variety of purposes: improved prevention, diagnosis, and treatment of human and animal diseases; enhanced production of food and energy; environmental remediation; and even microfabrication of electronic circuits. It is likely that some work in each of these diverse areas offers significant dual-use possibilities. (NRC 2006: 222)

The increasing capacity to construct living organisms *de novo* through the rapidly growing field of synthetic biology simply expands this potential security concern further (Ball 2004; Check 2006; Tucker and Zilinskas 2006; Garfinkel et al. 2007).[9]

[9] It is important to acknowledge that the potential risks of the misuse of advances in the life sciences are not universally accepted. On a technical level, some argue that "Mother Nature is the best terrorist," so there is little reason for terrorists or less technologically advanced countries to do more than take advantage of the highly dangerous pathogens already abundantly available in nature; a review of these discussions and debates may be found in Frerichs et al. (2004). On the level of general policy, some consider concerns about bioterrorism to be part of a general U.S. tendency to exaggerate the threat of terrorism involving weapons of mass destruction (WMD); a detailed and skeptical assessment of this phenomenon related to biological issues may be found in Leitenberg (2005). Among

Many assessments of dual use issues nevertheless conclude that the research within these broad categories posing genuine risks will be quite limited (NRC 2006; Steinbruner et al. 2007; NSABB 2007). The NSABB, an advisory body to the U.S. Department of Health and Human Services, for example, makes a distinction between "dual use research" and the narrower "dual use research of concern," with the latter defined as "research that, based on current understanding, can be reasonably anticipated to provide knowledge, products, or technologies that could be directly misapplied by others to pose a threat to public health and safety, agricultural crops and other plants, animals, the environment, or materiel" (NSABB 2007:17).[10] This report, which is focused on education for the broad community of life scientists about the general problem rather than issues of policy and oversight where precise definitions become important because of their practical effects, uses the more general term.

Even if their own research poses no actual risks of misuse, scientists in many areas of life sciences are potentially affected. Perceptions about a particular field or focus could lead to policy actions with both direct and indirect effects on the research enterprise.[11] All life scientists are potentially affected by public perceptions about security and other risks arising from continuing advances in knowledge and capabilities. Despite the recent attention to dual use and other security issues, however, the level of awareness among the broad community of life scientists is low (Rappert 2008, NRC 2009d). Moreover, the life sciences have had far fewer connections to the national security branches of government than other areas of science such as nuclear physics or parts of engineering; this lack of experience makes communication between scientists and security experts more difficult (NRC 2004a). This has led to a number of recommendations about the need for scientists to become aware of and engaged in discussions about dual use issues and their roles in helping mitigate the potential risks of misuse in ways that will enable scientific progress to continue (NRC 2004a,b; IAP 2005; NRC 2006; WHO 2007).

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the U.S. responses to the anthrax letters was a massive increase in funding for research activities of the type most likely to raise concerns (Klotz and Sylvester 2009); some critics of the biodefense program have charged that the "defensive" work has become increasingly problematic in terms of compliance with the BWC (Leitenberg, Leonard, and Spertzel 2003). Other research suggests that absorbing and using new technology may require substantial tacit knowledge that is not easily transferred or acquired by states or terrorists, particularly through published research results (Vogel 2006, 2008).

[10] It is dual use research of concern that would be subject to the NSABB's proposed oversight framework (NSABB 2007).

[11] An example from the United States is the Select Agent program, which regulates research with a list of over 80 biological agents and toxins. For an account of the development and implementation of the program, including its future directions, see NRC 2009e.

THE "CULTURE OF RESPONSIBILITY" IN THE LIFE SCIENCES

In responding to dual use issues, the life sciences can draw on a strong tradition of addressing societal concerns by developing norms and practices to govern scientific research. The iconic case is the response to the development of gene splicing techniques in the early 1970s that would enable research with recombinant DNA (rDNA) from different organisms. A Gordon Conference in June 1973 discussed safety issues related to laboratory workers and a number of well-known scientists sent letters to *Science* and *Nature* calling for a temporary moratorium on rDNA experiments until the potential risks could be assessed. This was followed by the famous 1975 Asilomar Conference where scientists gathered to discuss the safety of manipulating DNA from different species.[12] The conference concluded that most rDNA work should continue, but appropriate safeguards in the form of physical and biological containment procedures should be put in place. In 1976 the National Institutes of Health (NIH) issued *Guidelines for Research Involving rDNA Molecules* to govern the conduct of NIH-sponsored recombinant DNA research and established a mechanism for reviewing proposed experiments in this field. More recently, the 13-year Human Genome Project (1990–2003) created the Ethical, Legal, and Social Implications (ELSI) Program at the outset of its work to explore how advances in genetics intended to improve human health could proceed while addressing a variety of potential societal concerns.[13]

Over time, the life sciences community has developed three strands of ethical and safety norms and practices to guide research. The primary approaches are described briefly here and in somewhat more detail at the beginning of Chapter 3. Researchers working with dangerous biological agents and toxins developed a set of *biosafety* practices to protect the health of laboratory workers and avoid accidental or inadvertent releases.[14] With a more explicitly normative focus, *bioethics* is a diverse, interdisciplinary field that includes several distinct areas, such as ethical issues related to the practice of medicine, or the ethical controversies brought about by advances in biology and medicine. *Responsible conduct*

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[12] The Asilomar Conference addressed only the *accidental* creation of recombinant microorganisms with increased virulence and other dangerous properties. It did not address the *deliberate* creation of such organisms for offensive applications in warfare and terrorism, although security concerns had also been raised (Wade 1980; Budianski 1982).

[13] For further information, see http://www.ornl.gov/sci/techresources/Human_Genome/project/hgp.shtml. NIH and the Department of Energy devoted three to five percent of their annual project budgets to studying ELSI issues.

[14] This is also the primary channel by which research technicians, who have access to and knowledge of dangerous pathogens that make them important participants in laboratory biosecurity, are included in the process of creating a culture of responsibility (NRC 2009e).

of research (RCR) is a U.S.-based approach that requires students at various levels who are funded by the NIH and the National Science Foundation (NSF) to receive education about professional standards in areas such as plagiarism and data fabrication, as well as wider societal issues and responsible conduct.

Depending on their field, where they are studying, and where they are in their education, students may learn about some or all of these norms and practices through formal coursework or more informal mechanisms, including mentoring by senior researchers. Taken together, these are the primary avenues by which life scientists acquire their knowledge of responsible conduct and broader community norms, which is often referred to as a "culture of responsibility."

It is important to note that not all students in the life sciences receive education about responsible conduct and the quality and comprehensiveness of what is available varies widely. This has led to a number of proposals and activities, within particular countries and internationally, to expand and improve the quality of education that life scientists are receiving about responsible conduct. At the same time, as discussed below and in Appendix C, there is growing support for education as part of efforts to address the security concerns related to advances in the life sciences. Exploring the ways in which these efforts might complement one another is one of the themes running through this report.

THE LIFE SCIENCES AND THE "WEB OF PREVENTION"

Dual use issues pose serious policy challenges, in particular the search for a mix of measures at the national, regional, and international level that can mitigate the risks of misuse while enabling continuing scientific advances—and ensuring the availability of those advances to all. This is part of broader security challenges posed by several key features of biological weapons.[15] For example, the wide availability of biological materials in nature, including the most dangerous pathogens, and the ability of these materials to replicate means that there are no technical "chokepoints" where restricting access to materials poses a formidable barrier to acquisition.[16] As already discussed, the broad array of life sci-

[15] A more detailed discussion of the fundamental differences between biological and nuclear materials, the two most frequently compared types, may be found in *Responsible Research with Biological Select Agents and Toxins* (NRC 2009e:116-117).

[16] It is also important to note that constructing a biological weapon capable of inflicting mass casualties involves much more than simply isolating or synthesizing a dangerous pathogen. Instead, a biological weapon is a system that requires the processing of a pathogenic agent into a concentrated wet slurry or a dry powder, the development of a suitable chemical formulation to stabilize the agent during storage and delivery, and the engineering

ences research that might be of proliferation concern covers many fields and types of research institutions; commercial research and applications are equally diverse, so that monitoring potentially relevant activities would be a formidable task. And the rapid pace of scientific advances makes it difficult to keep abreast of potential risks and then to craft legal or regulatory measures that can stay current and relevant without unduly hampering scientific research.[17]

The nature of the policy challenges posed by biological weapons and bioterrorism has led to widespread recognition that the risks should be addressed through the creation of a "web of prevention."[18] The concept of the web includes legal measures, such as national laws and regulations, and international agreements. The fundamental international norm against biological weapons is embodied in the Geneva Protocol, which was signed in 1925 and entered into force in 1928, and the Biological and Toxin Weapons Convention (BWC), which was signed in 1972 and entered into force in 1975.[19] Ambassador Masood Khan of Pakistan, president of the BWC's sixth review conference, commented that:

> The BWC has had marked success in defining a clear and unambiguous global norm, completely prohibiting the acquisition and use of biological and toxin weapons under any circumstances. The preamble to the

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and construction (or acquisition) of a delivery system capable of disseminating the agent as a fine-particle aerosol over a large area. Each step in the development process is complex, and the integrated weapon system requires realistic field testing.

[17] For an example of an effort to design such a legal/regulatory regime see Steinbruner et al. (2007).

[18] As discussed in Appendix C, the term "web of prevention" was coined by the International Committee of the Red Cross (ICRC) as part of its Biotechnology, Weapons, and Humanity campaign launched in 2002. Graham Pearson had proposed a "web of deterrence," but he did not address dual use research issues (Pearson 1993).

[19] The formal title of the Geneva Protocol, which prohibits first use of chemical and biological weapons, is the "Protocol for the Prohibition of the Use in War of Asphyxiating, Poisonous or Other Gases, and of Bacteriological Methods of Warfare." The BWC's formal title is the "Convention on the Prohibition of the Development, Production and Stockpiling of Bacteriological (Biological) and Toxin Weapons and on Their Destruction." Article I of the BWC states:

> Each State Party to this Convention undertakes never in any circumstances to develop, produce, stockpile or otherwise acquire or retain:
> (1) Microbial or other biological agents, or toxins whatever their origin or method of production, of types and in quantities that have no justification for prophylactic, protective or other peaceful purposes;
> (2) Weapons, equipment or means of delivery designed to use such agents or toxins for hostile purposes or in armed conflict.

UN Security Council Resolution 1540, passed in 2004, adds a further binding international commitment against support for non-state actors seeking to acquire weapons of mass destruction or the means of their delivery.

> Convention so forcefully states: the use of disease as a weapon would be "repugnant to the conscience of mankind." It captures the solemn undertaking of the states parties "never in any circumstances to develop, produce, stockpile or otherwise acquire or retain" such weapons. With 155 states parties,[20] the treaty is not universal, but no country dares argue that biological weapons can ever have a legitimate role in national defense. Such is the force of the treaty (Khan 2006).

The BWC calls on its member states to develop national implementing legislation to support the treaty with formal legal measures. In addition, countries may have an array of laws and regulations that address biological weapons and bioterrorism directly or contribute indirectly by governing various aspects of research and commercial activities.

But the concept of a web also includes an important role for measures of self-governance drawing on the culture of responsibility among those doing life sciences research, as well as guidelines and other voluntary practices that could have both government and nongovernment components. Sustained engagement by scientists and scientific organizations is thus considered an essential component of the broader strategy. In the United States, for example, a number of reports from the National Research Council have made this argument (NRC 2004a,b, 2006, 2007a, 2009d,e,f), and the theme is echoed in the U.S. *National Strategy for Countering Biological Threats* released in late 2009.[21]

> Life scientists are best positioned to develop, document, and reinforce norms regarding the beneficial intent of their contribution to the global community as well as those activities that are fundamentally intolerable. Although other communities can make meaningful contributions, only the concerted and deliberate effort of distinguished and respected life scientists to develop, document, and ultimately promulgate such norms will enable them to be fully endorsed by their peers and colleagues. (White House 2009:8)

Other international organizations have become engaged in dual use issues as well, including the ethical and normative dimensions and efforts to expand the engagement of scientists. In 2005 the World Health Organization (WHO) released a background paper, *Life Science Research: Opportunities and Risks for Public Health*, as an initial step toward increas-

[20] As of August 2010, the BWC had 163 states parties.

[21] The scientific community also has an important role as advisors to policy-makers about trends in science with dual use implications, assessments of the balance of potential risks and benefits in new and continuing activities, and the implications of proposed policies for both science and security (NRC 2004a,b, 2006, 2007a, 2009e,f).

ing engagement in the issue (WHO 2005).[22] WHO then held a workshop in October 2006 on "Life Science Research and Global Health Security." The workshop report recommended the creation of a standing scientific advisory group to the WHO Director-General on biosecurity, including both improved biosafety and responsible oversight of research (WHO 2007). The WHO also undertook a number of collaborative activities, including regional workshops addressing both biosafety and biosecurity issues. The OECD Global Futures Programme created a website (www.biosecuritycodes.org) to provide information about national and international activities. The involvement of organizations such as the WHO and the OECD added the important elements of global health and economic development to the more traditional security concerns represented by the BWC in considering dual use issues.

THE EMERGENCE OF EDUCATION AS A FOCUS

As already discussed, in spite of the interest in increasing the awareness of scientists and the recognition of the importance of self-governance and norms of responsible conduct, the vast majority of life scientists remain unengaged in dual use issues. This has led to an increasing focus on education as an essential foundation for effective development and implementation of a web of prevention. A longer account of efforts to promote engagement, especially in the last decade, by national and international scientific organizations, and the growing support for education on the part of international bodies such as the WHO, UNESCO, and the OECD and from the activities associated with the operation and implementation of international agreements such as the BWC, may be found in Appendix C. A few examples, which underscore the importance of connections between formal and informal components of the web, are provided here.

In 2002, following the collapse of efforts to negotiate a protocol to the BWC to provide verification of treaty compliance, the states parties agreed to a series of meetings before the next full treaty review conference in 2006. Each year focused on a different topic and included both a one- or two-week meeting of experts and a one-week meeting of the states parties. The program of intersessional meetings was continued between 2007 and 2010. In 2005 and 2008 the topics of the intersessional meetings were directly relevant to the interests of scientists. The 2005 meeting focused

[22] Much earlier, in May 1967 the WHO's World Health Assembly had approved a statement that "scientific achievements, and particularly in the field of biology and medicine—the most humane science—should be used only for mankind's benefit, but never to do it any harm" (WHO 1967).

on the "content, promulgation, and adoption of codes of conduct for scientists." The 2008 meeting addressed:

1. National, regional and international measures to improve biosafety and biosecurity, including laboratory safety and security of pathogens and toxins; and
2. Oversight, education, awareness raising, and adoption and/or development of codes of conduct with the aim of preventing misuse in the context of advances in bio-science and bio-technology research with the potential of use for purposes prohibited by the Convention.

A number of international scientific organizations were invited to make formal presentations to the plenary sessions in 2005 and 2008. There were also opportunities for informal sessions and personal interactions. All of these served to raise the visibility of the issues within the international diplomatic and security community.

The meetings in 2005 and 2008 provided a focal point around which efforts to raise awareness and engagement by the life sciences community could organize. For example, with an eye to the 2005 BWC meetings, the IAP Biosecurity Working Group decided to focus its first effort on drafting a statement of principles that could provide the basis for efforts by academies and other science bodies to develop codes of their own rather than attempting to develop a full-blown IAP code of conduct. In part this reflected a view that codes are most effective when those adhering to them have some sense of "ownership" and that this is best achieved when codes come from local or national sources with whom people have closer, more direct ties. "Education and information" is one of the core elements that any code should address: "Scientists should be aware of, disseminate information about and teach national and international laws and regulations, as well as policies and principles aimed at preventing the misuse of biological research" (IAP 2005).[23] The statement was introduced in Geneva in draft form during the experts meeting and the final version, endorsed by 69 IAP member academies, was released in time for the states parties meeting at the end of the year.

In addition to the 2005 statement, the IAP Working Group organized two international conferences on biosecurity, one in 2005[24] and one

[23] The other elements are Awareness, Safety and Security, Accountability, and Oversight. The full statement may be found at http://www.interacademies.net/Object.File/Master/5/399/Biosecurity%20St..pdf.

[24] Just over fifty participants from twenty developed and developing countries took part in the first forum, which included both plenary sessions and day-long parallel sessions devoted to specific topics—codes of conduct, "sensitive" information and publication policy, and research oversight—that enabled in-depth discussion. Although the participants were

in 2008.[25] Both meetings were done in cooperation with other international scientific organizations—the International Council for Science, the InterAcademy Medical Panel, and several international scientific unions. Each forum took place in the early spring before the BWC experts meeting, and each served as an important convening mechanism to help prepare for the meetings, to share information among individuals and groups working on dual use issues, and also to encourage scientific organizations to become more active generally. A significant portion of the progress in engaging the international scientific community in dual use issues described in Appendix C can be attributed to opportunities provided by occasions such as the BWC meetings and the ability of nongovernmental organizations to make productive use of them.

Organization of the Remainder of the Report

Chapter 2 offers a brief introduction to the results of research on the science of learning about more engaged and interactive approaches to education. Chapter 3 addresses the first part of the committee's charge, assessing the current extent of education on dual use issues internationally and the range of online materials available to support this education, and presents the committee's findings. Chapter 4 then takes up the other parts of the committee's charge, the gaps and needs with regard to current dual use education, and the committee's conclusions and recommendations about how to address them. It relies on the discussions during the Warsaw workshop, supplemented by additional examples and materials gleaned from other sources.

largely scientists, they also included people from a number of the other policy projects on biosecurity, as well as staff from the International Committee of the Red Cross (ICRC), the WHO, and the OECD. The agenda and participants list, as well as other information and copies of the presentations, may be found at http://www.nationalacademies.org/biosecurity. The IAP draft statement was discussed extensively during the small group session on codes of conduct and revised in response to the comments and suggestions.

[25] More than eighty participants from thirty-one countries, as well as the BWC, UNESCO, WHO, UN headquarters, the ICRC, and the OECD, attended the meeting hosted by the Hungarian Academy of Sciences in Budapest. The participants discussed the challenges and opportunities to: (1) build a culture of responsibility within the science community regarding biosecurity; (2) identify standards and practices for research oversight; and (3) provide scientific advice to governments and international organizations and develop the role of the science community in global governance. The working group on building the culture of responsibility focused most of its time on issues related to dual use education. An international committee appointed by the National Research Council of the U.S. National Academies prepared a report of the meeting (NRC 2009f).

REFERENCES

African Union. 2006. The Cairo Declaration. Extraordinary Conference of the African Ministerial Council on Science and Technology (AMCOST), ET/AU/EXP/ST/Decl/13(II)\REV.1. 23-24 November.

Aldous, P. 2001. Biologists urged to address risk of data aiding bioweapon design. *Nature* 414(6861):237-238 as cited in R. A. Zilinskas and J. B. Tucker (2002), Limiting the contribution of the open scientific literature to the biological weapons threat. *Journal of Homeland Security*. Available at www.homelandsecurity.org/journal/Articles/tucker.html.

Arora, N., and S. H. Leppa. 1994. Fusions of anthrax toxin lethal factor with shiga toxin and diptheria toxin enzymatic domains are toxic to mammalian cells. *Infection and Immunity* 62(11):4955-4961.

Ball, P. 2004. Synthetic biology: Starting from scratch. *Nature* 431:624-626.

Boyce, N. 2002. Should scientists publish work that could be misused? *U.S. News and World Report* 132(22):60.

Budianski, S. 1982. US looks to biological weapons. Military takes new interest in DNA devices. *Nature* 297:615-616.

Carter, A. B., J. M. Deutch, and P. D. Zelikov. 1998. Catastrophic terrorism: Tackling the new danger. *Foreign Affairs* 77(6):80-94.

Cello, J., A. V. Paul, and E. Wimmer. 2002. Chemical synthesis of poliovirus cDNA: Generation of infectious virus in the absence of natural template. *Science* 297(5583):1016-1018.

Centers for Disease Control and Prevention and National Institutes of Health. 2007. *Biosafety in Microbiological and Biomedical Laboratories*, 5th ed. (L. C. Chosewood and D. E. Wilson, eds.). Washington, DC: U.S. Government Printing Office.

Check, E. 2006. Synthetic biologists try to calm fears. *Nature* 441:388-389.

Epstein, G. L. 2001. Controlling biological warfare threats: Resolving potential tensions among the research community, industry, and the national security community. *Critical Reviews in Microbiology* 27(4):321-354.

Frerichs, R. L., R. M. Salerno, K. M. Vogel, N. B. Barnett, J. Gaudioso, L. T. Hickok, D. Estes, and D. F. Jung. 2004. *Historical Precedence and Technical Requirements of Biological Weapons Use: A Threat Assessment.* SAND2004-1854. Albuquerque, NM: Sandia National Laboratories.

Garfinkel, M. S., D. Endy, G. L. Epstein, and R. M. Friedman. 2007. Synthetic genomics: Options for governance. *Industrial Biotechnology* 3(4):333–365.

Gibbs, M. J., J. S. Armstrong, and A. J. Gibbs. 2001. Recombination in the hemagglutinin gene of the 1918 "Spanish flu." *Science* 293(5536):1842-1845.

Government Office for Science, Department for Innovation, Universities, and Skills. 2007. Rigour, Respect, and Responsibility: A Universal Ethical Code for Scientists. Available at http://www.berr.gov.uk/files/file41318.pdf.

IAP. 2005. Statement on Biosecurity. Available at http://www.interacademies.net/CMS/About/3143.aspx.

IOM (Institute of Medicine). 2001. *Preserving Public Trust: Accreditation and Human Research Participant Protection Programs*. Washington, DC: National AcademyPress.

IOM. 2010. *Ethical Issues in Studying the Safety of Approved Drugs*. Washington, DC: National Academies Press.

ICSU (International Council for Science). 2006. First Meeting of ICSU Committee on Freedom and Responsibility in the Conduct of Science (CFRS). Available at http://www.icsu.org/Gestion/img/ICSU_DOC_DOWNLOAD/1220_DD_FILE_Minutes_CFRS_1stMeeting.pdf.

ICSU. 2008. *Freedom, Responsibility and Universality of Science*. Paris: ICSU.

Khan, M. 2006. Preparations and expectations. Presentation to the United Nations General Assembly First Committee, Sixth Review Conference of the Biological and Toxin Weapons Convention, October 11, New York.

Klotz, L. C., and E. J. Sylvester. 2009. *Breeding Bio Insecurity: How U.S. Biodefense Is Exporting Fear, Globalizing Risk, and Making Us All Less Secure.* Chicago: University of Chicago Press.

Kuhlau, F., S. Eriksson, K. Evers, and A. T. Hoglund. 2008. Taking due care: Moral obligations in dual use research. *Bioethics* 22(9):477-487.

Leitenberg, Milton. 2005. *Assessing the Biological Weapons and Bioterrorism Threat*. Carlisle Barracks, PA: Strategic Studies Institute, U.S. Army War College.

Leitenberg, M., J. Leonard, and R. Spertzel. 2003. Biodefense crossing the line. *Politics and the Life Sciences* 22(2):2-3.

Meselson, M. 2000. The Problem of Biological Weapons. Symposium on Biological Weapons and Bioterrorism. National Academy of Sciences, Washington, DC, May 2.

NRC (National Research Council). 1995. *On Being a Scientist*, 2nd ed. Washington, DC: National Academy Press.

NRC. 2002. *Scientific and Medical Aspects of Human Reproductive Cloning*. Washington, DC: National Academies Press.

NRC. 2004a. *Biotechnology Research in an Age of Terrorism*. Washington, DC: National Academies Press.

NRC. 2004b. *Seeking Security: Pathogens, Open Access, and Genome Databases*. Washington, DC: National Academies Press.

NRC. 2005a. *Guidelines for Embryonic Stem Cell Research*. Washington, DC: National Academies Press.

NRC. 2006. *Globalization, Biotechnology, and the Future of the Life Sciences*. Washington, DC: National Academies Press.

NRC. 2007a. *Science and Security in a Post 9/11 World: A Report on Regional Discussions between the Science and Security Communities*. Washington, DC: National Academies Press.

NRC. 2009a. *On Being a Scientist*, 3rd ed. Washington, DC: National Academies Press.

NRC. 2009b. *A New Biology for the 21st Century*. Washington, DC: National Academies Press.

NRC. 2009c. *Environmental Health Sciences Decision Making: Risk Management, Evidence, and Ethics: Workshop Summary*. Washington, DC: National Academies Press.

NRC. 2009d. *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: National Academies Press.

NRC. 2009e. *Responsible Research with Biological Select Agents and Toxins*. Washington, DC: National Academies Press.

NRC. 2009f. *2nd International Forum on Biosecurity: Report of an International Meeting, Budapest, Hungary, March 30-April 2, 2008*. Washington, DC: National Academies Press.

NRC. 2010. *Guide for the Care and Use of Laboratory Animals*, 8th ed. Washington, DC: National Academies Press.

NSABB (National Science Advisory Board for Biosecurity). 2007. Proposed Framework for the Oversight of Dual Use Life Sciences Research: Strategies for Minimizing the Potential Misuse of Research Information. Available at http://www.biosecurityboard.gov/news.asp.

OECD (Organization for Economic Cooperation and Development). 2007. *OECD Best Practice Guidelines on Biosecurity for BRCS (Biological Resource Centres)*. Paris: Organization for Economic Cooperation and Development. Available at http://www.oecd.org.

OECD. 2009. *The Bioeconomy to 2030: Designing a Policy Agenda*. Paris: Organization for Economic Cooperation and Development. Available at http://www.oecd.org.

Pearson, G. S. 1993. Prospects for chemical and biological arms control: The Web of Deterrence. *The Washington Quarterly* 16(2):145-162.

Rappert, B. 2004. *Towards a Life Science Code: Countering the Threats from Biological Weapons.* Bradford Briefing Paper No. 13, September. Available at http://www.brad.ac.uk/acad/sbtwc.

Rappert, B. 2008. The benefits, risks, and threats of biotechnology. *Science & Public Policy* 35(1):37–44.

Rusek, B. 2009. Clarifying Biosecurity Terminology. Pp.98-166 in *Biosecurity: Origins, Transformations and Practices.* B. Rappert and C. Gould, eds. Basingstoke, UK: Palgrave Macmillan.

Steinbruner, J. D., E. D. Harris, N. Gallagher, and S. M. Okutani. 2007. *Controlling Dangerous Pathogens*. College Park, MD: Center for International Security Studies at Maryland.

Tucker, J. B., and R. Zilinskas. 2006. The Promise and Perils of Synthetic Biology. *The New Atlantis* 12(1):25-45.

UNESCO (United Nations Educational, Scientific and Cultural Organization). 1999. Declaration on Science and the Use of Scientific Knowledge. World Conference on Science, Budapest, Hungary, June 26-July 1. Available at http://www.unesco.org/science/wcs/eng/declaration_e.htm.

Vogel, K. M. 2006. Bioweapons proliferation: Where science studies and public policy collide. *Social Studies of Science* 36(5):659-690.

Vogel, K. M. 2008. Framing biosecurity: An alternative to the biotech revolution model? *Science and Public Policy* 35(1):45-54.

Wade, N. 1980. Biological weapons and recombinant DNA. *Science* 208:271.

Wang, X. G., G. H. Zhang, C. X. Liu, Y. H. Zhang, C. Z. Xiao, and R. X. Fang. 2001. Purified cholera toxin b subunit from transgenic tobacco plants possesses authentic antigenicity. *Biotechnology and Bioengineering* 72(4):490-494.

Wein, L. M., and Y. Liu. 2005. Analyzing a bioterror attack on the food supply: The case of botulinum toxin in milk. *Proceedings of the National Academy of Sciences USA* 102(28):9984-9989.

Wheelis, M., L. Rózsa, and M. Dando. 2006. *Deadly Cultures: Biological Weapons Since 1945*. Cambridge, MA: Harvard University Press.

White House. 2009. *National Strategy for Countering Biological Threats.* Available at http://www.whitehouse.gov/sites/default/files/National_Strategy_for_Countering_BioThreats.pdf.

WHO (World Health Organization). 1967. World Health Assembly. Resolution WHA20.54.

WHO. 2004. *Laboratory Biosafety Manual* (3rd ed.) Geneva: World Health Organization. Available at http://www.who.int/csr/resources/publications/biosafety/WHO_CDS_CSR_LYO_2004_11/en/.

WHO. 2005. *Life Science Research: Opportunities and Risks for Public Health*. Geneva: World Health Organization. Available at http://www.who.int/csr/resources/publications/deliberate/WHO_CDS_CSR_LYO_2005_20.pdf.

WHO. 2006. *Biorisk Management: Laboratory Biosecurity Guidance.* Geneva: WHO.

WHO. 2007. Scientific Working Group on Life Science Research and Global Health Security: Report of the First Meeting. Geneva: WHO. Available at http://www.who.int/csr/resources/publications/deliberate/WHO_CDS_EPR_2007_4.

Zilinskas, R. A., and J. B. Tucker. 2002. Limiting the Contribution of the Open Scientific Literature to the Biological Weapons Threat, *Online Journal of Homeland Security* (December). Available at http://www.homelandsecurity.org/newjournal/articles/tucker.html.

2

A Primer on the Science of Learning

INTRODUCTION

This chapter provides an overview of efforts to change the emphases and direction of education in the life sciences. The intent is to provide both a context in which to place efforts at education about dual use issues and to summarize what is known about effective teaching and learning strategies in service of developing effective education strategies for dual use issues. While the preponderance of learning science evidence comes from studies on K-12 and undergraduate populations, the fundamentals of how people learn can be applied to graduate students, postdoctoral researchers, faculty, other instructional staff, and technical staff (NRC 2000). The United States played a leading role in the early research and implementation and this is reflected in the literature and examples cited. A number of examples also demonstrate the growing international interest in making fundamental changes in life sciences education.

The New Biology and Education

A collective vision for an integrated and synthetic approach to the life sciences is emerging that offers a rich context for education about dual use issues. *A New Biology for the 21st Century*, a report of the National Research Council (NRC) of the U.S. National Academy of Sciences, calls for a problem-based approach to the life sciences that addresses societal issues ranging from human and environmental health to sustainable energy and food production (NRC 2009b; Figure 2-1). The focus on

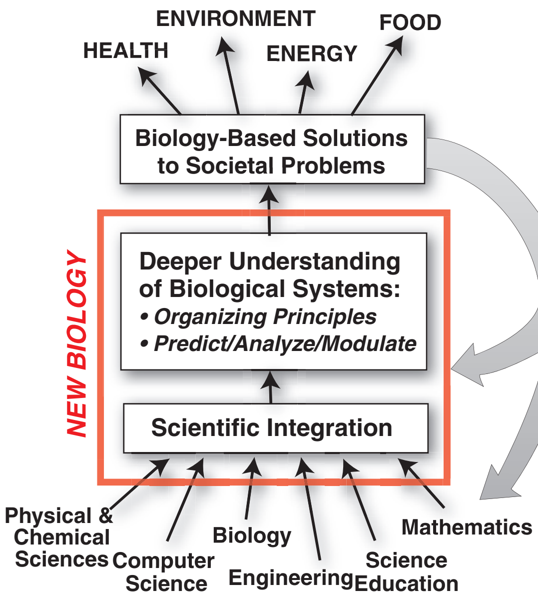

FIGURE 2-1 What is the new biology?
SOURCE: Committee on a New Biology for the 21st Century.

researchers' responsibilities for the biology underlying pressing societal needs naturally widens the conversation to responsibilities for discerning unanticipated, deleterious consequences. Preparation of life scientists to solve real-world problems requires attention to an integration of the many fields that inform the life sciences and underscores the need for science education informed by the learning sciences (NRC 2000, Labov, Reid, and Yamamoto 2010, Jungck et al. 2010, Brewer and Smith, in press).

Following the publication of several seminal reports (e.g., NRC 1998, 2003a; National Science Foundation (NSF) 1996), undergraduate science education has received sustained attention in the past two decades, although the transformation called for in numerous more recent reports is far from a reality. Echoing the societal relevance of research called for in *A New Biology for the 21st Century*, the call for action by the American Association for the Advancement of Science (AAAS) in *Vision and Change in Undergraduate Biology Education* (Brewer and Smith, in press) emphasizes the need for teaching and learning to move from memorization to conceptual knowledge and application and from abstraction to real world relevance. Education about dual use issues, appropriately integrated into undergraduate and graduate curricula, provides a vehicle for engaging students in real world problems of substantial societal importance. For example, students learning about either ribosomes and translation or plant defense mechanisms might explore the mechanism of action of neurotoxin ricin, found in the seeds of the castor bean plant, *Ricinus communis*, to develop a deeper understanding of basic biology and to grapple with the history of the nefarious use of this lethal substance. Encounters with a range of dual use scenarios throughout a biologist's education would reinforce the importance of applying problem solving skills to socially relevant issues. Likewise, for students who take only a single life science course before pursuing other educational and career interests, some exposure to dual use issues would also raise awareness of the culture of responsibility and ethics in science that could be informative as they make decisions as citizens and possibly policy makers (e.g., NAE 2009; NRC 2009a,c).

Learning experiences for premedical students and medical students in the United States are being reexamined in light of the *Scientific Foundations for Future Physicians*, a competency-based blueprint for pre-medical and medical students from the Association of American Medical Colleges and the Howard Hughes Medical Institute (AAMC/HHMI 2009) emphasizing skills (competencies), knowledge, values, and attitudes. The explicit inclusion of ethics in that report opens the door for addressing dual use issues. Considering the large percentage of entering college students intent on pursuing a medical career, including materials about dual use issues in curricular revisions guided by the AAMC/HHMI competencies could be both timely and far reaching.

Curricular revision is driven at many levels, ranging from individual instructors to departments, schools of science, and universities, in addition to professional societies and state and national policies. The Academy of Medical Educators, for example, has developed professional standards for medical educators with a goal of informing curriculum development. Similarly, over the past decade the American Psychological Association and ABET, Inc. (formerly the Accreditation Board for Engineering and Technology) have established standards for undergraduate education in their disciplines with an emphasis on student learning outcomes.[1] Thus, numerous venues and vehicles exist to engage the broader life sciences community in integrating dual use issues into the improvement of life sciences education that is currently underway.

APPROACHES TO EFFECTIVE EDUCATION

The science of human learning has advanced significantly over the last several decades. The convergence of advances in the learning sciences

[1] "Learning outcomes" are defined as "specific, measurable learning goals," and "learning goals" as "what students will know, understand, and be able to do" (Handelsman, Miller, and Pfund 2007:20).

with the transformation of the life sciences as a discipline is enabling potentially profound and far reaching changes in science education.

Context for Education Reform

The concept of education reform in the life sciences is not new and clarion calls for reform can be found long before the post-Sputnik drive to improve science education in the 1960s. What is striking in 2010 is the gathering momentum and convergence of efforts to improve education in the life sciences. In the 1990s, a consortium of life science professional societies formed the Coalition for Education in the Life Sciences (CELS) and worked within the context of the disciplinary societies to increase attention to evidence-based approaches to teaching and learning (Liao 1998).

As a result of all of these efforts, biology education research is emerging as a field where researchers with both a deep disciplinary knowledge of the field and expertise in educational research are moving post-secondary life sciences education forward (Bush et al. 2008). Building on and acknowledging the importance of what has been learned to improve undergraduate biology education, over 500 life sciences educators and administrators gathered in Washington, DC, in July 2009 for the AAAS Vision and Change in Undergraduate Biology Education summit, calling for relevant, outcome-oriented, active biology learning focused on deep conceptual understanding in student-centered environments with ongoing feedback and assessment (Woodin, Carter, and Fletcher 2010; Brewer and Smith, in press).

Two current drivers in life sciences education are the growing recognition of the centrality of interdisciplinary approaches and a focus on competences and learning outcomes. *A New Biology for the 21st Century* is only one of many reports highlighting the substantial role of other disciplines in leveraging life science research and the concomitant need for effective undergraduate education that leads to deep knowledge within the field and fluency in related areas (NRC 2003a, 2007b, 2009b,g). In the context of Figure 2-1, education about dual use issues aligns as an emerging social science application supported by disciplinary learning, which is undergirded by the physical sciences, engineering, mathematics, and learning sciences.

Learning outcomes and competences are beginning to drive undergraduate curriculum development, and in the case of medical education, post-graduate education (AAMC/HHMI 2009). In Europe, for example, the Bologna Process was developed as a means to: (1) facilitate mobility of students and educational staff at European universities, (2) improve career preparation, (3) increase access to high-quality higher education, and (4) develop international consensus on what constitutes high-quality education at the postsecondary level (more information may be found at the Bologna process website www.ond.vlaanderen.be/hogeronderwijs/bologna/about/). Forty-seven European countries, as well as the European Commission, the Council of Europe, and European Center for Higher Education of UNESCO participate in the European Higher Education Area. The basic goals of the process are to arrive at common learning outcomes for students in different college degree programs with input from students, recent graduates, employers, and faculty. The Bologna Process was piloted in the United States through a program called Tuning that involved Utah, Indiana, and Minnesota faculty, students, recent graduates, and employers (Adelman 2009). Biology was one of the degree programs that was "tuned" in the project, and, as in Europe, assessments are being developed to determine whether or not specific competencies or learning outcomes have been achieved. Finding ways to include the competencies essential for responsibly addressing dual use issues among the competencies for undergraduate biology education could be a promising approach to promoting their widespread adoption.

Background on the Science of Learning

Applying relevant findings from the science of learning to curriculum and materials development will enhance the likelihood of achieving desired outcomes. There is strong evidence that "active learning" approaches enhance learning generally (NRC 2000). A critical component of active learning is that the learner, rather than the instructor, is at the center and focus of all activities in the classroom, laboratory, or field. Learner-centered environments are more likely to be collaborative, inquiry-based, and relevant (Brewer and Smith, in press). There is still a place for short, carefully structured lectures, but the instructor becomes primarily a guide providing effective learning materials and expertise as needed. Michael (2006) summarizes several characteristics of active learning processes:

- Having students engage in some activity that forces them to reflect upon ideas and how they are using those ideas.
- Requiring students to regularly assess their own degree of understanding and skill at handling concepts or problems in a particular discipline (this process is also called "metacognition" (NRC 2000).
- Attaining knowledge by participating or contributing.
- Keeping students mentally, and often physically, active in their

learning through activities that involve them in gathering information, thinking, and problem solving.

As this list suggests, there are numerous teaching strategies to support active learning, ranging from in-class problem solving to case studies to learning from original investigations which they design in whole or in part (see http://bioedlinks.com for examples and resources for active learning pedagogies in undergraduate life science classrooms). A number of these strategies are discussed in the next section. The variety of strategies enable active learning approaches that can be implemented in classes of any size, including large introductory courses.

Several findings from the learning sciences can inform education about dual use issues. For example, to be well understood, factual knowledge must be placed in a conceptual framework. Framing learning in the sciences as four intertwined strands of proficiency provides a sound basis for creating effective teaching and learning experiences across all levels of education, including the primary grades (NRC 2007b):

- Understanding scientific explanations;
- Generating scientific evidence;
- Reflecting on scientific knowledge; and
- Participating productively in science.[2]

This model emphasizes the integration of learning about process and content in effective instruction. There are many opportunities for learners to engage with conceptual material, while being deeply involved in laboratory work. Thus laboratory work is not an add-on or distraction from content mastery, but rather one of many pathways to both factual knowledge and deeper conceptual understanding (NRC 2005b). Social and ethical responsibility, as well as biological content, can readily be integrated in laboratory learning, whether it is a formal undergraduate laboratory experience or graduate-level research (NRC 2009a; NAE 2009).

Building in time for reflection, as called out in the third strand above, is an essential component of effective approaches to learning. To date, this is the only practice that has been demonstrated to result in the student gains in understanding the nature of science (NRC 2005b, 2008). Reflection involves the opportunity to engage in the exploration of understandings with other learners and a teacher, and in giving students opportunities to become more aware of their own levels of learning.

[2] While the report cited, *Taking Science to School* (NRC 2007b), addresses grades K-8, for example, the principles articulated in that report have direct implications and applications for students at the secondary and postsecondary levels.

Numerous studies have demonstrated the value of "metacognition" or self-monitoring in learning. Many teaching and learning strategies engage the learner in metacognitive practice. As discussed below, active learning, properly implemented, encourages metacognition. Given the complexities of the social and ethical dimensions of dual use, it would be important to include various forms of reflection time—ranging from deliberate breaks in lectures that provide such opportunities to exercises that structure and guide reflection—in new curricula.

The importance of engaging learners' prior understanding as they encounter new material is another key insight from the science of learning (NRC 2000) with implications for education about dual use issues. Understanding is constructed on a foundation of existing conceptual frameworks and experiences. Prior understanding can support further learning. In some cases, however, it can also lead to the development of pre- or misconceptions that may act as barriers to learning. Prior understandings also can be influenced by culture, which has implications for the development of dual use curricular materials for an international audience (NRC 2008).

Conceptual change often requires explicit instruction and takes time. Often a learner is faced with too many disconnected ideas too quickly to be able to take meaning from them and change a previously held conception. And the literature on learning suggests that humans are not adept at making connections between disparate fields or types of knowledge unless they are specifically helped to do so through education (NRC 2000).

Curricular and Materials Development

Curricula can be designed to engage students in key scientific practices: talk and argument, modeling and representation, and learning from investigations (NRC 2008). Starting with learning outcomes is the first step in curriculum design, as illustrated by the following set of design principles for curricula that include laboratory learning experiences:

- Begin with clear learning outcomes in mind.
- Thoughtfully sequence laboratory learning in the flow of classroom science instruction.
- Integrate learning of science content with learning about the processes of science.
- Incorporate ongoing student reflection and discussion (NRC 2005b).

Efforts to shape learning outcomes also provide opportunities to incorporate aspects of social responsibility.

Learning outcomes inform instructional and also assessment strategies, both of which are most useful when considered and integrated into curriculum development at the outset. Assessment can be both formative and summative. Formative assessment occurs during the learning process, providing feedback for the teacher and learner on learning progress. Approaches to formative assessment include a variety of methods to provide quick feedback, such as:

- "minute papers" where students write a response to an instructor query about a confusing point or concept;
- the use of "clicker" devices so that individual responses to a problem become the collective judgment of the learners and visible to both the instructor and the students (NRC 2003b);[3] and
- online feedback, which is now available in many course management tools.

With online feedback, for example, a student selects an answer to a problem and immediately receives information about the accuracy of the response (see http://www.biology.arizona.edu/mendelian_genetics/mendelian_genetics.html). A highly developed version of this type of feedback would operate like an intelligent tutor. Adjustments can be made in response to formative assessment, with the resulting iterative process enhancing knowledge attainment and the formation of a meaningful conceptual framework for the learner. Formative assessments typically are not graded by the instructor; instead, students may be awarded points for completing them. Formative assessments can also serve as a means for helping students learn about the benefits and uses of peer review (NRC 2003b).

Summative assessment, conducted at the end of a learning and teaching experience, provides information to students about their learning gains and to faculty and programs about the overall success of the effort and can be used to inform later implementation of the curriculum. Concept inventories, critical thinking rubrics, and curriculum-specific, pre- and posttests are examples of summative assessment tools.

Without assessment that is closely aligned to learning outcomes, it is difficult to gather evidence about the effectiveness of curriculum. For example, if the desired outcome is critical thinking, assessment that is limited only to measuring students' content knowledge would not provide sufficient information about whether the goal had been attained and the instructional emphasis geared to developing critical thinking was effective.

Higher-order thinking, including critical thinking, problem solving,

[3] For evidence on clickers, see Wood (2004) and Caldwell (2007).

synthesis, and transfer, the goals of many educational efforts, are certainly desirable skills for those who will potentially face dual use issues. Transfer, for example, is demonstrated when a learner can apply what he or she has learned to a new problem. Including multiple opportunities for undergraduates, graduate students, and researchers to apply what they have learned about dual use across several settings, courses or laboratory experiences could help foster this capacity for transfer.

Less is known about ethical development than about science learning in college-age students and other young adults. In an early and still influential study of intellectual and ethical development among college students, William Perry (1970) described a series of phases through which young adults move, beginning with "dualism/received knowledge," in which there is a clear right or wrong. "Multiplicity/subjective knowledge" follows with the stance that everyone has her or his own opinion about an ethical situation. In the third stage, "relativism/procedural knowledge," the individual relies on disciplinary reasoning methods. An individual who reaches the stage of "commitment/constructed knowledge" can also integrate knowledge from others with personal experience and reflection.

Lee Shulman built on Perry's work in developing a framework for the integration of ethical and intellectual development (http://www.carnegiefoundation.org/elibrary/making-differences-table-learning). In Shulman's interpretation of learning, an individual progresses through the following six stages:

- Engagement and Motivation
- Knowledge and Understanding
- Performance and Action
- Reflection and Critique
- Judgment and Design
- Commitment and Identity (2002:37)

Whereas Perry's model assumes a linear progression through the stages of ethical development, Shulman argues that these stages can be viewed as a web or circle and individuals can move in various pathways through the stages. Shulman's concepts could be useful in framing learning outcomes for dual use curriculum and associated assessments.

In addition to considering ethical and intellectual development, attention to the learner's culture and environment is also important for effective curriculum development. As discussed above, prior understandings will affect how an individual interacts with the materials, and learning is enhanced when the learner perceives the relevance of the material. The need for relevance underscores the importance of making materials adaptable to local settings and individual circumstances, for example by providing instructors with a range of suggestions for adapting a common curriculum to their own settings.

Examples of Active Learning Approaches

An example of active, collaborative, hands-on learning with particular relevance to dual use issues is the International Genetically Engineered Machine (iGEM) competition for undergraduates (http://igem.org/). College and university teams use synthetic biology to address a complex problem and enter competitions with their solutions. Students are deeply engaged in actively learning about molecular biology and genetic engineering applications, areas with substantial potential for misuse. Along with the science learning, iGEM provides an ideal setting for education about dual use issues and, as described further in Chapter 4, some initiatives to integrate dual use issues are already under way.

Problem-based learning and case studies provide additional active learning strategies with relevance to dual use education. For example, Gijbels (2008) analyzed the effectiveness of problem-based learning in the context of Barrows' six core characteristics. The characteristics are (1) student-centered, (2) small-group work, (3) tutor as a guide, (4) authentic, real-world problems, (5) problems as a tool to develop problem solving skills and acquire conceptual understanding, and (6) students acquire new information through self-directed learning (Barrows 1996). These characteristics were developed originally for medical education but since applied across a wide range of disciplines and age levels.[4]

Gijbels' metanalysis of the literature indicated cognitive gains from this approach to learning. In addition, attention to the social aspects of learning is essential to success. The group development process requires explicit attention, as many students may be reluctant to invest time in the interpersonal process and to make an effort to deal with differences of opinion. Developing group work skills in problem-based learning would have benefits for learners who may encounter real world dual use issues.

Cases are often used by faculty employing a problem-based method of instruction. A study by the National Center of Case Study Teaching in Science of 101 faculty who used case studies reported that case-based

[4] "The primary difference between PBL [problem-based learning] and inquiry-based learning relates to the role of the tutor. In an inquiry-based approach the tutor is both a facilitator of learning (encouraging/expecting higher-order thinking) and a provider of information. In a PBL approach the tutor supports the process and expects learners to make their thinking clear, but the tutor does not provide information related to the problem—that is the responsibility of the learners " (Savery 2006:16).

teaching increased students' ability to consider multiple perspectives (91.3 percent agreed), understand more deeply (90.1 percent), think critically (88.8 percent), make connections (82.6 percent), and address ethical issues (61.3 percent). A review of the case study literature by Lundberg (2008) indicates that cases have particular value in helping students to gain knowledge and understanding of how global, ethical, and societal contexts influence interdisciplinary issues.

Cases do not teach themselves, however, and need to be carefully structured for both the instructor and the learner. Teaching notes for instructors are valuable additions and can provide information about how the case can be adapted to different settings. Learning goals should be clearly stated and should be of a scale appropriate for the specific case. It is important to consider how success or progress toward obtaining the stated goals could be assessed. The length of time and materials needed for the case should be provided.

Cases that involve multiple participants lend themselves to role playing. A key advantage of role playing is that individuals can adopt and argue from a stance without obligation to make their own position known from the start. Evidence supporting the usefulness of cases in developing multiple perspectives comes from a study of a case where students assumed roles as counselors, medical practitioners, and individuals infected with HIV (Foster et al. 2006). In this case, online conferencing tools allowed students to interact internationally, including students in the United States and Zimbabwe who were interviewed in the study.

Connecting to real world problems is an important feature of both case and problem-based strategies and several dual use case studies are already available (see Chapter 3). Writing has also been shown to enhance learning. For example, students who write about how they are going to solve a physics problem (a metacognitive strategy), are more effective in mastering introductory level physics problem solving than those who start with equations.

Making ideas visible through concept mapping or other visualizations is another way to support metacognition. A concept map provides a venue for students to connect their ideas and potentially identify misconceptions. Simplified models that capture core ideas work best.

The active learning strategies described above are a subset of the many approaches now in practice. Froyd (2008) classified these approaches into eight categories and rated them according to the evidence for their ease of implementation and effectiveness in enhancing student learning (Table 2-1). His analysis also draws attention to the question of cost-effectiveness and scaling of different practices, an important consideration for developers of education about dual use issues.

TABLE 2-1 Effectiveness of Promising Practices in Undergraduate Education

Promising Practice	Rating with Respect to Implementation Standards	Rating with Respect to Student Performance Standards
1: Prepare a Set of Learning Outcomes	Strong	Good
2: Organize Students in Small Groups	Strong	Strong
3: Organize Students in Learning Communities	Fair	Fair to Good
4: Scenario-based Content Organization	Good to Strong	Good
5: Providing Students Feedback through Systematic Formative Assessment	Strong	Good
6: Designing In-Class Activities to Actively Engage Students	Strong	Strong
7: Undergraduate Research	Strong or Fair	Fair
8: Faculty-Initiated Approaches to Student-Faculty Interactions	Strong	Fair

SOURCE: Adapted from Froyd (2008); scale: fair < good < strong.

Technology-Enabled Learning

Online technologies are making it possible for high-quality curricular materials to be developed and then shared with a broad audience, a particularly promising approach for international curricula if attention is paid to necessary adaptations. Given the overwhelming evidence in support of the effectiveness of active learning, modules that will be technology enabled can be designed to be interactive, keeping in mind the evidence for effective teaching and learning from the learning sciences. Simply reading about dual use issues on a Web page is unlikely to bring about the cognitive and behavioral and performance changes desired. In addition, technology and bandwidth availability need to be carefully considered as target audiences are being developed. For example, in some settings cell phone access is available although Internet connectivity is absent.

Technology provides the opportunity for students and instructors to collaborate on a learning activity internationally, as seen with the HIV case study (Foster et al. 2006). As discussed further in Chapter 4, the social networking tools of Web 2.0 are being increasingly adapted and incorporated to enable varied forms of discussion and engagement. Problem-based learning has been adapted for technology-enabled learning in a variety of ways. Problem solving in a large-enrollment biochemistry class at the University of New Mexico, for example, has been adapted to an online environment to facilitate discussions (Anderson, Mitchell, and Osgood 2008). Small groups participated in online discussions with discussions monitored by tutors. A tracking system was devised to assess the students' problem-solving strategies, providing a model for assessment of online, active learning.

Other examples of high-quality, peer-reviewed learning environments that are online are being recognized by the AAAS with the *Science* Prize for Online Resources in Education (SPORE).[5] The interactive work in the geoscience community that blends workshops and online collaborative tools to enhance geoscience education is one model to consider (Manduca et al. 2010). It is also an informative example of a community-wide effort to achieve educational goals. As with case studies, the experience of the geoscience community reinforces the importance of building resources for instructors alongside the teaching materials themselves (see, for example, http://serc.carleton.edu/NAGTWorkshops/index.html).

Researchers are currently investigating whether environments that combine and integrate online and face-to-face learning and interactions (also called "blended environments") are more effective than either approach alone. In one study from higher education settings supported by the U.S. Department of Education, a meta-analysis of 51 studies found that, "on average, students in online learning conditions performed better than those receiving face-to-face instruction (Means et al. 2009:ix). The biggest differences were found for those cases of blended learning versus only face-to-face instruction. Because blended learning often involves more time and attention from instructors, however, it is not certain how much of the impact comes from the technology.

Teaching the Teachers/Promoting Professional Development

Developing education modules about dual use issues is unlikely to be effective without parallel professional development for faculty. Further, providing evidence of the effectiveness of active learning pedagogies alone has been demonstrated to be insufficient to change how faculty teach (Henderson, Finkelstein, and Beach 2010). At a local level, university centers for teaching and learning provide opportunities to engage faculty in learning about effective teaching practices and encouraging the implementation of new pedagogies. Many of these programs focus on graduate

[5] More information may be found at http://www.sciencemag.org/special/spore/.

students and postdoctoral students, as well as faculty, which have been shown to be a particularly effective means of encouraging change. The Preparing Future Faculty program, which ran from 1993 to 2003 in the United States, is one example of a national effort that worked at the local level to provide graduate students and postdoctoral students with the skills and confidence to institute effective teaching practices.[6]

Many professional societies offer workshops for new faculty, education symposia, education booths, and other venues to raise awareness about effective teaching practices and to provide recognition of individuals who engage in this work. The physics community has a long-standing workshop for new faculty, as does the American Society for Microbiology. As described further in Chapter 4, the Howard Hughes Medical Institute and the U.S. National Academies have an annual summer institute for faculty from research intensive universities that has been carefully structured to ensure that faculty follow through with new teaching practices after leaving the institute (see http://www.academiessummerinstitute.org/). BioQuest (http://bioquest.org) and SENCER (Science Education for New Civic Engagements and Responsibilities—http://sencer.net) are two national initiatives that are focusing on professional development for faculty in the context of enhancing student learning. Project Kaleidoscope's (PKAL) Faculty for the 21st Century (http://www.pkal.org/activities/F21.cfm) has focused on developing leadership skills in pretenured faculty who are interested in changing undergraduate science education both locally and nationally. Networks of faculty established through professional society workshops allow for ongoing information exchange and support, such as a coalition of scientific and education organizations founded to confront challenges to teaching evolution (Chow and Labov 2008). These are examples of scaling efforts; additional information about these and other efforts to improve undergraduate teaching and learning may be found at http://bioedlinks.com.

Professional life science research societies in the United States already have substantial investment in and commitment to education efforts (Liao 1998). As discussed further in Chapter 4, these are promising venues for

[6] "The PFF initiative was launched in 1993 as a partnership between the Council of Graduate Schools (CGS) and the Association of American Colleges and Universities (AAC&U). During a decade of grant activity, from 1993-2003, PFF evolved into four distinct program phases, with support from The Pew Charitable Trusts, the National Science Foundation, and The Atlantic Philanthropies. During this time, PFF programs were implemented at more than 45 doctoral degree–granting institutions and nearly 300 "partner" institutions in the United States. While the grant periods have expired, the Council of Graduate Schools continues to provide administrative support to existing programs and to those wishing to develop new PFF programs" (Council of Graduate Schools website, http://www.preparing-faculty.org/default.htm#about. Accessed 29 August 2010).

raising awareness about education modules for dual use issues while providing the necessary support for faculty to implement these modules.

International Examples of Support for Active, Inquiry-Based Learning

Almost all of the research and real world examples cited above relate to the United States. The move to transform how science is taught is not confined to one country. In addition to the Bologna process, there are efforts in individual countries and institutions around the world to introduce new approaches to teaching and learning about science. At the international level, the conferences of international unions and other professional organizations routinely feature symposia, workshops, or other events that focus on improving education in particular fields or sharing the results of discipline-specific projects. Some of these take the form of specialized workshops. For example, among the programs conducted by the International Brain Research Organization, a global network for neuroscience research, are "Teaching Tools Workshops," a series intended to provide the framework and the methods for teaching neuroscience in African countries. The third workshop was held in Kenya in September 2010; the materials have a strong focus on learner-centered approaches (Weeks 2008).

Also at the international level, since 2001 the IAP, the Global Network of Academies of Sciences, has carried out a series of activities to promote what it terms "Inquiry-Based Science Education" through a program led by the Chilean Academy of Sciences. Although the focus is on primary and secondary education, as already suggested, the basic approach can be adapted to post-secondary settings. A recent event under this initiative involved a workshop organized in May 2010 by the French Academy of Sciences on "Science and Technology Education in School." This seminar was intended for trainers and decision makers from educational systems outside Europe who wished to learn about the methods and the tools developed in France. The objective was to help them in the renewal of science education and the implementation of an inquiry-based approach in their classrooms. A workshop on "Transition of the Inquiry-Based Science Education Methodology from Primary to Secondary School" organized in Santiago, Chile, in early 2010 was followed with a conference on the same topic in York, England, in October 2010 under the joint sponsorship of the Chilean Academy of Sciences, ALLEA (the federation of European academies of sciences and humanities), and IANAS (the InterAmerican Network of Academies of Sciences). A condensed handbook, *Inquiry-Based Science Education: An Overview for Educationalists*, is available in English, French and Spanish and offers educators and authorities, especially ministries of education, arguments in support of inquiry-based learning. A list of other activities and publications involving academies from all parts of the world may be found at the IAP website (http://www.interacademies.net/CMS/Programmes/3123.aspx).

SUMMARY

The development of education modules about dual use issues will benefit from the application of the science of learning, creative use of online education, and explicit planning to "teach the teachers." Developing clear learning outcomes for the dual use modules is a first step. This report broadly frames these outcomes, which can be articulated in more specific terms for individual modules. Active learning strategies are more likely to engage the learners and support retention. The real world nature of dual use problems can be effective in engaging students and supporting their learning, if attention is paid to the social learning aspects of group work, as well as the cognitive aspects of learning. Online modules will allow the scaling of the educational effort and active learning strategies and assessment tools can be embedded into the technology-enabled delivery. Here the context of the learner needs to be considered and online modules need to be adaptable in different settings. Finally, explicit planning for faculty development is essential, ranging from including teaching tips in the curricular material to workshops at professional research society meetings.

REFERENCES

Adelman, C. 2009. *The Bologna Process for U.S. Eyes: Re-Learning Higher Education in the Age of Convergence*. Washington, DC: Institute for Higher Education Policy.

Anderson, W. L., S. M. Mitchell, and M. P. Osgood. 2008. Gauging the gaps in student problem-solving skills: assessment of individual and group use of problem-solving strategies using online discussions. *CBE-Life Sciences* 7:254-262.

AAMC (Association of American Medical Colleges) and HHMI (Howard Hughes Medical Institute). 2009. *Scientific Foundations for Future Physicians: Report of the AAMC-HHMI Committee*. Washington, DC: AAMC.

Barrows, H. S. 1996. Problem-based learning in medicine and beyond: A brief overview. Pp. 3-11 in *Bringing Problem-Based Learning to Higher Education: Theory and Practice*, L. Wilkerson and W. Gijselaers, eds. New Directions for Teaching and Learning Series. San Francisco: Jossey-Bass.

Brewer, C., and D. Smith (eds.) In press. Vision and Change in Undergraduate Biology Education: A Call to Action. Washington, DC: American Association for the Advancement of Science.

Bush, S. D., N. J. Pelaez, J. A. Rudd, M. T. Stevens, K. D. Tanner, and K. S. Williams. 2008. Science faculty with education specialties. *Science* 322:1795-1796.

Caldwell, J. E. 2007. Clickers in the Large Classroom: Current Research and Best-Practice Tips. *CBE Life Sci Educ* 6(1):9-20.

Chow, I., and J. B. Labov. 2008. Working Together to Address Challenges to the Teaching of Evolution. *CBE Life Sci Educ* 7(3):279-283.

Foster, A., V. Manokore, M. Phillips, M. Lundeberg, Y. Gwekwerere, M. Bergland, and K. Klyczek, 2006. Understanding, confidence, perceptions, constraints, and affordances within a case-based multimedia environment. Pp. 2533-2540 in *Proceedings of World Conference on Educational Multimedia, Hypermedia and Telecommunications,* E. Pearson and P. Bohman, eds., Chesapeake, VA: AACE.

Froyd, J. E. 2008. White Paper on Promising Practices in Undergraduate STEM. National Research Council. Available at http://www7.nationalacademies.org/bose/PP_Commissioned_Papers.htm.

Gijbels, D. 2008. Effectiveness of Problem-Based Learning. National Research Council. Available at: http://www7.nationalacademies.org/bose/PP_Commissioned_ Papers.htm.

Handelsman, J., S. Miller, and C. Pfund. 2007. *Scientific Teaching.* New York: Freeman.

Henderson, C., N. Finkelstein, and A. Beach. 2010. Beyond dissemination in college science teaching: An introduction to four core change strategies. *Journal of College Science Teaching* 39(5):18-25.

Jungck, J. R., H. D. Gaff, A. P. Fagen, and J. B. Labov. 2010. "Beyond *BIO2010*: celebration and opportunities" at the intersection of mathematics and biology. *CBE Life Sci Educ* 9(3):143–147.

Labov, J. B., A. H. Reid, and K. R. Yamamoto. 2010. Integrated biology and undergraduate science education: A new biology education for the twenty-first century? *CBE Life Sci Educ* 9(1):10-16.

Liao, L. (ed.). 1998. *Professional Societies and the Faculty Scholar: Promoting Scholarship and Learning in the Life Sciences*. Madison, WI: Coalition for Education in the Life Sciences.

Lundberg, M. A.. 2008. Case Pedagogy in Undergraduate STEM: Research We Have; Research We Need. National Research Council. Available at http://www7.nationalacademies.org/bose/PP_Commissioned_Papers.html.

Manduca, C. A., D. W. Mogk, B. Tewksbury, R. H. MacDonald, S. P. Fox, E. R. Iverson, K. Kirk, J. McDaris, C. Ormand, and M. Bruckner. 2010. On the cutting edge: Teaching help for geoscience faculty. *Science* 327:1095-1096.

Means, B., Y. Toyama, R. Murphy, M. Bakia, and K. Jones. 2009. *Evaluation of Evidence-Based Practices in Online Learning: A Meta-Analysis and Review of Online Learning Studies*. Washington, DC: U.S. Department of Education.

Michael, J. 2006. Where's the evidence that active learning works? *Advances in Physiology Education* 30:159-167.

NAE (National Academy of Engineering). 2009. *Ethics Education and Scientific and Engineering Research: What's Been Learned? What Should Be Done? Summary of a Workshop*. Washington, DC: National Academies Press.

NRC (National Research Council). 1998. *Transforming Undergraduate Education in Science, Mathematics, Engineering, and Technology.* Washington, DC: National Academy Press.

NRC. 2000. *How People Learn: Brain, Mind, Experience, and School (Expanded Edition)*. Washington, DC: National Academies Press.

NRC. 2003a. *Bio 2010: Transforming Undergraduate Education for Future Research Biologists*. Washington, DC: National Academies Press.

NRC. 2003b. *Evaluating and Improving Undergraduate Teaching in Science, Technology, Engineering, and Mathematics*. Washington, DC: National Academies Press.

NRC. 2005b. *America's Lab Report: Investigations in High School Science*. Washington, DC: National Academies Press.

NRC. 2007b. *Taking Science to School*. Washington, DC: National Academies Press.

NRC. 2008. *Ready, Set, Science*! Washington, DC: National Academies Press.

NRC. 2009a. *On Being a Scientist*, 3rd ed. Washington, DC: National Academies Press.

NRC. 2009b. *A New Biology for the 21st Century*. Washington, DC: National Academies Press.

NRC. 2009c. *Environmental Health Sciences Decision Making: Risk Management, Evidence, and Ethics: Workshop Summary*. Washington, DC: National Academies Press.

NRC. 2009g. *Research at the Intersection of the Physical and Life Sciences.* Washington, DC: National Academies Press.

NSF (National Science Foundation). 1996. Shaping the Future: New Expectations for Undergraduate Education in Science, Mathematics, Engineering, and Technology (NSF 96-139). Arlington, VA: National Science Foundation.

Perry, W. 1970. *Forms of Intellectual and Ethical Development n the College Years*. New York: Holt, Rinehart, and Winston.

Savery, J. R. 2006. Overview of problem-based learning: Definitions and distinctions. *The Interdisciplinary Journal of Problem-based Learning* 1:1 (Spring):9-20.

Shulman, L. S. 2002. Making differences: A table of learning. *Change* 34(6):36-44.

Weeks, J. C. Learner-centered teaching in neuroscience: Some resources. IBRO IAC-USNC 1st Teaching Tools School & Workshop in Neuroscience. Dakar, Senegal. June 30-July 3. Photocopy.

Wood, W. 2004. Clickers: A teaching gimmick that works. *Developmental Cell* 7:796-798.

Woodin, T., V. C. Carter, and L. Fletcher. 2010. Vision and Change in Biology Undergraduate Education, A Call for Action—Initial Responses. *CBE Life Sci Educ* 9(2):71-73.

3

Current Conditions: Establishing a Baseline About Education on Dual Use Issues

INTRODUCTION

As part of its charge, the committee sought to develop an understanding of:

- The extent to which dual use issues are currently being included in postsecondary education (undergraduate and postgraduate) in the life sciences;
- In what contexts that education is occurring (e.g., in formal coursework, informal settings, as stand-alone subjects or part of more general training, and in what fields); and
- What educational materials addressing dual use research in the life sciences already exist.

The committee's primary information gathering took place during an international workshop, held over two-and-a-half days in November 2009 at the Polish Academy of Sciences in Warsaw; the agenda and participants list for the workshop may be found in Appendix B. Two background papers commissioned for the meeting provided an indication of the types and frequency of biosecurity-related courses or modules at a selection of higher education institutions in the United States, the United Kingdom, Europe, Japan, and Israel (Revill et al. 2009), as well as examples of currently available online educational materials (Vos 2009). These background papers, distributed to all of the participants before the workshop, several other reports made available on the project website (American

Association for the Advancement of Science [AAAS] 2008; Biological and Toxin Weapons Convention [BWC] 2008; NRC 2009f; Federation of American Societies in Experimental Biology [FASEB] 2009; NAE 2009; National Science Advisory Board for Biosecurity [NSABB] 2008), and presentations at the workshop provided the basis for discussion. To inform its work further in preparing the report, the committee and the project staff also drew on additional studies and resources, which are cited and discussed in the body of this report.

THE CURRENT STATE OF EDUCATION ON DUAL USE AND BIOSECURITY

Background: Current Channels for Education About Responsible Research and Research Ethics

As described briefly in Chapter 1, there are currently three major strands through which life scientists may receive "education" about professional standards and responsible scientific conduct. All of these approaches are included in the baseline surveys described in the rest of the chapter. The education varies widely in form and content, ranging from formal coursework to specialized, sometimes one-time training, to informal instruction or mentoring as part of laboratory work. And the education reaches only a portion of life science students, technical personnel, or faculty. Issues related to raising awareness among life scientists about dual use issues is thus related to larger issues of the type of education about research ethics and broader social responsibility that scientists should receive.

Biosafety is the set of practices that have developed over time to protect the health of laboratory workers and avoid accidental or inadvertent releases. This is also the primary channel by which research technicians, who have access to and knowledge of dangerous pathogens that make them important participants in laboratory security, receive their introduction to the culture of responsibility. Biosafety practices are codified in several national and international documents. The World Health Organization's (WHO) *Laboratory Biosafety Manual* (LBM) was first published in 1983, with a third edition in 2004 (WHO 2004).[1] In the United States, the

[1] To complement the manual, WHO published *Biorisk Management: Laboratory Biosecurity Guidance* in 2006, which attempts to "strike a balance" between longstanding biosafety practices and newer concepts of biosecurity by recommending a "biorisk management approach" to provide guidance to its member states in developing their own national approaches (WHO 2006:1). WHO defined *biorisk* as the "probability or chance that a particular adverse event (in the context of this document: accidental infection or unauthorized access, loss, theft, misuse, diversion or intentional release), possibly leading to harm, will occur" (WHO 2006:iii).

National Institutes of Health (NIH) and the Centers for Disease Control and Prevention first published the *Biosafety in Microbiological and Biomedical Laboratories (BMBL)* in 1984, with the 5th edition being published in 2007 (CDC and NIH 2007). The latest editions of both the LBM and BMBL include chapters introducing the principles of biosecurity. The European Committee for Standardization (CEN) facilitated the development by biosafety and biosecurity professionals of the 2008 *International Laboratory Biorisk Management Standard*, which adds a proposed voluntary management system to guide the implementation of specific biosafety and biosecurity practices (CEN 2008). To date the biosafety community has been the most engaged in dual use issues. In large part, this results from the nature of the research subject to biosafety, especially at higher containment levels, and from the impact dual use issues have had on research funding, practice, and sometimes regulation.

Bioethics is broadly concerned with the ethical questions that arise in the relationships among life sciences, biotechnology, medicine, politics, law, philosophy, and theology. The term has multiple meanings in different national and disciplinary contexts, from medical or clinical ethics to research ethics or to ethics related to specific topics, such as research with human subjects and the scope and content of education vary widely as a result. This is reflected in the results of the surveys reported in this chapter. In addition to many government and nongovernment efforts at the national and regional level, the UN Educational, Scientific, and Cultural Organization (UNESCO) has had programs in bioethics since the 1970s as part of its general efforts on the ethics of science and technology.[2] To date, with a few important exceptions, there has been little engagement by the bioethics community in dual use issues (Selgelid 2010).

Responsible conduct of research (RCR) is a loosely defined set of issues, policies and professional standards, and good research practices that emerged in the United States after the NIH mandated in 1989 that holders of certain training grants provide instruction in responsible conduct of research to their trainees in order to ensure integrity in research generally.[3] The policy came in response to congressional efforts to regulate research to prevent misconduct but also in response to the 1989 report from the Institute of Medicine that advocated such education (IOM 1989). RCR is also known widely as "research integrity," "scientific integrity," and even "research ethics." Some topics for RCR education were sug-

[2] Further information may be found at http://www.unesco.org/new/en/social-and-human-sciences/themes/bioethics/.

[3] The requirement was expanded to cover all training grant recipients in 1992 and expanded further in 2009. The 2009 policy document may be found at http://grants.nih.gov/grants/guide/notice-files/NOT-OD-10-019.html.

gested, but NIH did not recommend a curriculum or particular topics or format until November 2009; in addition to topics such as conflicts of interest and mentor/mentee responsibilities and relationships, the ninth topic is "the scientist as a responsible member of society, contemporary ethical issues in biomedical research, and the environmental and societal impacts of scientific research" (NIH 2009). In another important development in 2009, the National Science Foundation (NSF) issued a requirement for institutions to provide instruction in RCR to all trainees funded by or working with NSF-funded research projects. NSF supports major programs in the life sciences (biology, agricultural science), as well as in basic physical sciences (chemistry) and engineering, and mathematics that are increasingly playing important roles in life sciences research (NRC 2009g). Because NIH and NSF funding extends beyond the United States, the impact of these requirements is felt internationally. There has also been a conscious effort in recent years to expand RCR education internationally, as reflected in the Second World Conference on Research Integrity in Singapore in July 2010.[4]

Survey of In-Person Courses and Modules: Europe, Japan, UK, and Israel

A group of researchers at the University of Exeter, the University of Bradford, the National Defence Medical College of Japan, and the Landau Network Centro Volta in Italy have recently undertaken a program of activities to identify the biosecurity education available in multiple countries and assess potential needs and opportunities. As an important component of this project, Giulio Mancini, James Revill, and their colleagues conducted surveys in Europe, Japan, the United Kingdom, and Israel on the existence of biosecurity modules within a selection of university degree courses (Revill and Mancini 2008; Minehata and Shinomiya 2009; Minehata and Friedman 2009; Revill 2009; Revill et al. 2009).[5] The surveys included both undergraduate and master's degree courses and were chosen to include basic science classes in microbiology or molecular biology as well as applied biotechnology and industrial biology offerings. James Revill conducted an expanded survey in the United Kingdom by sampling not only university course offerings but also A-level high school courses, life science textbooks, and funding agency requirements (Revill

[4] The conference website is https://www.wcri2010.org/index.asp. One of the workshop's products, the "Singapore Statement on Research Integrity" (Second World Conference on Research Integrity 2010) may be found at http://www.singaporestatement.org/.

[5] A condensed version of the report on Europe, augmented with data from Japan and the United Kingdom, was prepared as a background paper for the workshop (Revill et al. 2009), and presented during one of the early plenary sessions.

2009). This information provides an indication of the frequency and content of biosecurity-related courses in these regions.

The surveys in Europe and Japan involved a review of the information available online for life sciences courses using the key words *biosecurity, dual-use, bioethics, biosafety, arms control,* and *codes of conduct*, along with follow-up discussions whenever possible with identified faculty and course coordinators.[6] Of the 142 courses at 57 universities in 29 countries sampled in Europe, the authors report that only three offered an optional module devoted specifically to biosecurity: Jagiellonian University in Poland, University of Vienna in Austria, and Uppsala University in Sweden (Mancini and Revill 2009). An additional 25 percent (36 courses) made at least a reference to biosecurity, particularly as part of a bioethics module. Modules covering a variety of bioethics and/or laboratory biosafety topics were identified more frequently in the sample—48 percent (68 modules) for bioethics and 19 percent (27 modules) for biosafety. Investigations of course syllabi and follow-up interviews revealed that these modules covered a wide range of both philosophical and practical issues; some individuals also indicated that aspects of laboratory biosafety were discussed elsewhere in degree programs. Only about 15 percent (21 courses) included specific references to biological weapons, arms control, or the Biological and Toxin Weapons Convention (BWC), although the limitations in online descriptions of course material and a low response rate to requests for follow-up interviews complicated the ability to draw firm conclusions on the extent these topics are covered.

In the United Kingdom, the survey produced a sample of 57 undergraduate and postgraduate courses at 31 universities (Revill 2009). As far as the author was able to determine from searching online and following up via email, 27 of the 57 courses identified offered some material on bioethics although only a few included topics relevant to biosecurity, 6 degree courses definitely included some material on biological warfare and weapons, one course was identified that included biosecurity issues, and none of the courses sampled included material on the BWC.

In Japan, the sampling process identified 197 life science degree courses at 62 universities across Japan, of which 98 were undergraduate and 99 were postgraduate (Minehata and Shinomiya 2009). Specific bioethics modules were identified in 70 percent of the courses (138). In contrast, only 3 biosecurity modules were noted, along with a few reported instances of references to biosecurity. There were only 18 cases of a specific biosafety module, but the authors comment that biosafety education in Japan is more frequently taught by means other than a single dedicated

[6] A detailed discussion of the methodology used in the surveys may be found in Revill and Mancini 2008.

module. As in Europe, the researchers found only limited mention of the international regimes to prohibit biological weapons (11 cases).

Of particular interest to the workshop, the surveys also examined biology course references to the term *dual use*. In Europe, approximately 20 percent of the courses surveyed did include such a reference, an additional 23 percent did not, and the results for the rest of the sample were unclear on the basis of the materials available. The authors further reported that attitudes varied among interviewed individuals with regard to the utility of teaching students about potential dual use issues in the life sciences. In Japan, on the other hand, the researchers report that bioethics content discussing the use and potential misuse of science was relatively common (94 cases), even if it was not explicitly framed in terms of "dual use." Indeed, a significant proportion of the individuals who responded to the researchers' requests for further information were unfamiliar with "dual use" as applied to the life sciences (17 of 24 respondents). In the United Kingdom, 8 degree courses offered material on dual use issues out of 57. Secondary school A-level biology course specifications likewise did not include specific references to biological weapons or to "dual use," although discussions of ethical, social, and environmental issues in biology were broadly encouraged.

A similar survey was conducted in Israel, in a partnership between the Bradford Disarmament Research Centre and the Institute for National Security Studies (INSS). The authors sampled the content of 35 biosafety and bioethics courses from six research universities in the country and reported that "there was no specific module on biosecurity found in this investigation, while 4 biosafety modules and 28 bioethics modules were discovered" (Minehata and Friedman 2009). The authors note, however, that Israel presents an example of a country with significant current opportunities for increasing education on biosecurity topics, including dual use issues. In 2008, the Steering Committee on Issues in Biotechnological Research in the Age of Terrorism, a joint project of the INSS and the Israel Academy of Science and Humanities, released its report *Biotechnological Research in an Age of Terrorism* (Israel Academy 2008). A number of the report's recommendations were subsequently enacted into law. The Council for Biological Disease Agent Research was established under the Regulation of Research into Biological Disease Agents Act, providing a top-down framework with the ability to support the implementation of biosecurity education (Friedman 2010).

In addition to the surveys cited above, a number of other surveys were being developed and implemented by the Bradford-Landau collaboration. Surveys for Ukraine, Morocco, Pakistan, and the Asia-Pacific were among the examples cited during the workshop or reported later (Rappert 2010; Sture and Minehata, in press). In addition to their role in providing information, the surveys were seen as part of a broader strategy to identify potential collaborators and raise awareness at the national and international level about the current state of education about dual use issues.

Another potential source of information about education on dual use issues is the Global Ethics Observatory (GEObs), a project of the United Nations Educational, Scientific and Cultural Organization (UNESCO).[7] The observatory is a system of databases with worldwide coverage in bioethics and other areas of applied ethics in science and technology such as environmental ethics, science ethics, and technology ethics. Submissions to the GEObs databases are voluntary, but the coverage is potentially global. One of the databases on Ethics Education Programs includes 230 programs across a wide range of ethics. Among the topics included in the Science Ethics category are Biological Weapons, Biosafety, Bioterrorism, and Dual Use. No programs were registered for which *dual use* was a keyword, one program in Belarus appeared for *biological weapons* and for *bioterrorism*, and two for *biosafety* (Belarus again and Côte d'Ivoire).

Survey of In-Person Courses and Modules and Attitudes Toward Education on Dual Use Issues in the United States

The prevalence of education on dual use issues has also been examined in the United States. With assistance from the Association of American Universities, the American Association for the Advancement of Science (AAAS) surveyed deans at colleges of medicine, veterinary medicine, nursing, public health, engineering, and graduate schools of arts and sciences on the existence of programs addressing dual use research in the life sciences. The survey results identified four categories of educational programs: education programs for scientists, biodefense policy courses, biosafety training programs, and bioterrorism preparedness courses for public health students. This survey, augmented by additional AAAS research, identified existing education programs at 14 universities that "specifically dealt with educating graduate or professional students in the biomedical sciences on dual use research issues" (AAAS 2008:3). These programs included lectures, case studies, simulations, and Responsible Conduct of Research (RCR) training modules; links to all these programs were made available on the AAAS website.[8] A meeting on "Professional and Graduate-Level Programs on Dual Use Research and Biosecurity for Scientists" subsequently held by AAAS in November 2008 augmented the results of the survey with discussions among experts that yielded addi-

[7] More information may be found at http://www.unesco.org/new/?id=20060.
[8] The material may be found at http://cstsp.aaas.org/dualuse.html.

tional information about gaps and made recommendations about how to fill them (AAAS 2008).[9]

In addition to this survey of existing U.S. university courses, AAAS and the National Research Council conducted a survey of scientists' attitudes towards biosecurity (NRC 2009d). The survey sampled 10,000 AAAS members in the life sciences, but the low response rate (approximately 20 percent) means that the results should not be generalized beyond those who responded to the survey. Among the respondents, 16 percent considered themselves to be doing research with dual use potential, while 15 percent (260 people) indicated that they had changed their behavior in some fashion due to dual use concerns, including changes to communication, research design, or collaborators. The surveyed scientists generally supported education about dual use issues, with 82 percent agreeing that professional societies should develop codes of conduct and 68 percent supporting additional lectures and materials on dual use life sciences research for university and college students. However, only 55 percent agreed that institutions should provide *mandatory* training, while 86 percent felt that the principal investigator of a laboratory should assume the primary responsibility for training lab personnel about dual use research and for assuring that any dual use implications of ongoing research had been appropriately considered.

Online Educational Materials

In addition to in-person courses and modules devoted to aspects of biosecurity identified in the surveys, the committee sought information about what online educational resources currently exist in the United States and internationally for use in undergraduate or postgraduate education.[10] A background paper commissioned from Cheryl Vos (2009), then with the Federation of American Scientists (FAS), provided summaries of the online resources that she identified. It was beyond the resources available to the committee to attempt a broader survey of published materials.

The online materials vary in length, target audience, and the way their content is presented. The modules, all of which were available as of December 1, 2010, include:

[9] The results of the survey and the meeting were described by AAAS staff member William Pinard in one of the opening plenary sessions.

[10] The materials might also be relevant for secondary school settings or in technical trainings courses but these are not the focus of the workshop and this report.

- *Case Studies in Dual-Use Biological Research,* Federation of American Scientists (USA) [http://www.fas.org/biosecurity/education/dualuse/]
- *Dual Use Dilemma in Biological Research*, Policy Ethics and Law Core of the Southeast Regional Center of Excellence for Emerging Infections and Biodefense (SERCEB) (USA) [http://www.serceb.org/dualuse.htm]
- *Biosecurity: Risks, Responses and Responsibilities,* Center for Arms Control and Non-Proliferation (USA) [http://www.armscontrolcenter.org/policy/biochem/biosecurity_educational_materials]
- *Educational Module Resource*, Bradford Disarmament Research Centre (UK), National Defence Medical College (Japan), and Landau Network Centro Volta (Italy) [http://www.dual-usebioethics.net]
- *The Life Sciences, Biosecurity and Dual Use Research: Dual Use Role Playing Simulation*, University of Exeter (UK), University of Bradford (UK), and University of Texas at Dallas (USA) [http://projects.exeter.ac.uk/codesofconduct/BiosecuritySeminar/Education/index.htm]
- *Biology and Security,* Student Pugwash USA (USA) [http://www.spusa.org/pubs/peace_security/biosecurity/index.html]

In addition, material on biosecurity is included as part of the website, Resources for Research Ethics Education (www.research-ethics.net), of the University of California, San Diego, Center for Research Ethics. It emphasizes U.S. legislation, includes questions and other resources for teaching ethics, and has links to other resources, including both the FAS and SERCEB online modules.

Both the FAS and SERCEB resources are designed to encourage students, researchers, and/or laboratory technicians to log in and work through the materials on their own with no additional guidance from an instructor. The SERCEB module is a single online presentation that is intended to require approximately 30 minutes to complete. The introductory content includes relatively brief overviews of the historical use of biological weapons, applicable international treaties such as the Biological Weapons Convention, and relevant U.S. laws such as the 2001 USA PATRIOT Act. The SERCEB module then takes the user through several commonly cited cases of research with dual use potential—including the chemical synthesis of the poliovirus genome (Cello, Paul, and Wimmer 2002), the characterization and reconstruction of the 1918 flu (Taubenberger et al. 2005; Tumpey et al. 2005), and the incorporation of a cytokine gene into mousepox (Jackson et al. 2001). In addition, the module takes the user through a hypothetical scenario in which a graduate student encounters dual use issues in her work. Several discussion and assessment questions are included at the end of the SERCEB module, and a certificate of completion can be generated and printed. The module was updated after an evaluation to reflect comments and suggestions from students, faculty members, and members of SERCEB institutional biosafety committees who had taken it and also from faculty who had assigned it to their students.

The FAS project is a more ambitious effort that currently includes eight modules focused primarily on case studies that exemplify potential questions about dual use issues that a researcher might encounter. The first module offers the same type of brief introduction to the issues provided by the SERCEB module, including a history of bioweapons and efforts to control them. The other modules include the three cases covered by the SERCEB modules and also cases involving antibiotic resistance, aerosol delivery, and RNA interference. A seventh module focuses on public reaction to scientific research, featuring Susan Ehrlich, a former state court judge and "public" member of the National Science Advisory Board for Biosecurity. The FAS modules concentrate on the real-life examples, including links to original scientific papers and videos of researchers discussing the results. Several discussion and assessment questions are included at the end of the modules, along with additional references and resources. One of the case studies has been translated into French, another into Chinese, and a third is being translated into Russian. Even though designed to be used as stand-alone resources, plans are also being made to develop resources for teachers to make it easier to integrate the modules into existing courses.

Biosecurity: Risks and Responsibilities is a video series whose "learning units" provide an introduction to biological weapons, bioterrorism, and the risk of misuse of legitimate biological research. It also has three case scenarios for the user to consider, as well as links to readings to supplement both the learning units and the case scenarios. Rather than focusing on dual use issues, *Biosecurity: Risks and Responsibilities* provides a detailed history of biological weapons and efforts to control them. There are four units currently available, and each unit is divided into sections. Two units provide a broad and comprehensive history of biological weapons use and development. The third unit, "Some Perils of Modern Biology," addresses dual use issues as well as the potential for deliberate efforts to harness modern biotechnology for weapons. The fourth unit contains detailed information to address the question, "How can hostile exploitation of biology be prevented?" including the major international agreements for biological and chemical disarmament and an array of other national and international measures. It also includes a discussion of the major nongovernmental organizations involved. The video format is often simply used to display text or bullet points, but on occasion it provides images to accompany the voiceover.

A separate section has additional materials for teachers, including a proposed learning strategy. "This strategy is suggested both for brief exposure to the materials (two one-hour class sessions and about ten hours of homework with materials downloaded from the website) and for initiating longer exposure based on the considerable material on the website (up to a one-half semester course)" (http://www.armscontrolcenter.org/policy/biochem/biosecurity_educational_materials, accessed July 10, 2010). The section for teachers cites research on learning to support a problem-based approach and offers additional resources through a password-protected site to which teachers can request access.

The content provided by the *Educational Module Resource* (EMR) specifically targets teachers, to assist them in learning about dual use topics and to provide materials for developing lesson plans to train scientists. The EMR is a major component of an ambitious education effort by researchers from the United Kingdom, Italy, and Japan. Much of the activity is carried out by the Bradford Disarmament Research Centre of the University of Bradford, which developed the EMR in cooperation with the Defence Medical College of Japan and the Landau Network Centro Volta. The EMR provides a substantial amount of material, including 21 sets of PowerPoint slides and links to associated briefing papers that provide additional information under main themes such as "The Threat of Biological Warfare (BW) and Biological Terrorism (BT) and the International Prohibition Regime," "The Dual-Use Dilemma and the Responsibilities of Life Scientists," "National Implementation of the BTWC," and "Building an Effective Web of Prevention to Ensure Benign Development." The material, which was originally available in English and Japanese, is now also available in Russian. The slide sets are intended to provide resources that can be used for anything from a short module focused on a single topic to a complete course that could extend over a number of weeks. As the project website notes: "We would like to emphasize that the educational module resource is not a Teaching Module rather it is a 'Module Resource.' Conscious that there is no one-size-fits-all approach, our educational module resource is designed to be 'modified and tailored to fit the requirements of different local educational contexts'" (http://www.dual-usebioethics.net/, accessed June 20, 2010).

The project has already developed a substantial network of international colleagues through an ambitious series of seminars around the world intended to both raise awareness and foster education on dual use issues (Rappert 2008, 2010). The surveys described above are another way in which this group identifies potential partners; it is hoped that they, like the informal network, will make use of the EMR. And as described further below, another Bradford colleague has developed a program to take advantage of advances in videoconferencing to provide an online train-the-trainer program based on the EMR.

The materials provided at *Life Sciences, Biosecurity and Dual Use Research: Dual Use Role Playing Simulation* and at *Biology and Security* focus on providing resources and discussion questions that would be used to conduct in-person activities with an instructor or leader. For example, the role playing simulation provides an accompanying PowerPoint lecture, information on 16 roles, and instructor notes. The exercise, which was developed as part of the series of seminars carried out by Rappert and Dando described below, covers issues in research publication, funding, oversight, and relevant policy documents.

The Student Pugwash USA *Biology and Security* materials include three hypothetical scenarios addressing ethics and dual use issues, along with accompanying discussion questions; also included is an "instant event idea" based on the plot synopsis and a video extract from the movie *Mission Impossible II*. The related discussion questions include one exploring the dual use nature of life sciences research.

Two additional online resources identified as focusing on broader but related biosecurity concerns do not appear to specifically target awareness-raising about potential dual use implications of research among practicing life scientists and life sciences students. The *BW Terrorism Tutorial* from the Nuclear Threat Initiative in the United States (http://www.nti.org/h_learnmore/bwtutorial/index.html) discusses the potential motivations of terrorists to use chemical and biological weapons (CBW), recent U.S. government responses to the CBW terrorism issue, examples of historical use of CBW, some information on classical BW threat agents and their categorization, hurdles to making a biological weapon, and prevention and response strategies (such as intelligence, export controls, legislation, lab security, and public health disease surveillance systems). The resource notes the dual use nature of some microbiological equipment and techniques but its focus is not on promoting an awareness of potential dual use implications that might arise from a scientist's research. The *Educational Module on Chemical & Biological Weapons Nonproliferation* from the Stockholm International Peace Research Institute in Sweden, the Vrije Universiteit Brussel (Free University Brussels) in Belgium, and the International Relations and Security Network in Switzerland (http://poli.vub.ac.be/cbw/index.html) includes basic and intermediate level modules on CBW, case studies of the Iraqi and Libyan chemical weapons programs, a historical overview of CBW, including a discussion of state programs, and incentives and penalties to prevent CBW proliferation, including trade and technology assistance, export controls, sanctions, arms control measures, and treaties. The resource is a discussion of CBW armament and disarmament issues focused on state weapons programs, rather than a resource to discuss the dual use implications that may arise from academic research.

A resource focused on dual use issues related to chemistry illustrates the potential contributions of international scientific organizations to education. The International Union of Pure and Applied Chemistry (IUPAC), with support from the Organization for the Prohibition of Chemical Weapons, developed *The Multiple Uses of Chemicals* to provide IUPAC chemists and chemistry teachers with materials intended to raise awareness about the Chemical Weapons Convention (CWC) and the responsibilities of scientists.

> Four working papers were produced that cover the many uses of chemicals, the CWC, the toxicology of selected chemical warfare agents, and codes of conduct. Approximately six pages long, the papers have been peer reviewed and tested in workshops in the UK, Russia, South Korea, and Italy. . . . Workshop participants have included chemistry students, teachers, university professors, diplomats, and specialists in chemical warfare. The four papers have been translated and are available in the working languages of the OPCW—Arabic, Chinese, French, English, Russian, and Spanish. The working papers are designed for use by university and high school chemistry teachers. They provide enough material for a one-hour lecture, or more. The papers were written with the objectives of promoting chemistry, providing information about the CWC, and encouraging debate. (Hay 2007)

The project also includes the creation of a website (www.iupac.org/multiple-uses-of-chemicals) and the design of several case studies. One feature of the project is the attention given to codes of conduct as a means to foster discussion and debate about what constitutes unethical conduct.

An additional resource released after the workshop in Warsaw is a short (7-1/2 minutes) video produced by the Office of Biotechnology Activities of the National Institutes of Health.[11] *Dual Use: A Dialogue* consists of a series of statements by leading U.S. scientists that provides an introduction to the concept of dual use and stresses the importance of scientists becoming engaged in dual use issues, including as part of education. The video could be used on its own as part of an introduction to dual use issues or could be an additional resource along with some of the more comprehensive materials described above. It could also be used in a number of the settings that form part of the strategic plan for education and outreach of the National Science Advisory Board for Biosecurity (NSABB 2008).

[11] The video may be found on the NSABB website at http://oba.od.nih.gov/biosecurity/, accessed July 10, 2010.

Discussions of the Baseline for Courses and Materials in Warsaw

During the workshop, participants offered more information to supplement the materials presented in the background papers about the current state of education about dual use issues and augment—at least anecdotally—the baseline of available data. Participants generally agreed that education on dual use issues is "patchy and ad hoc" and is frequently dependent on the efforts of local or national champions interested in the topic. As the background presented by Pinard on the United States and Revill and his colleagues on Europe, Israel, and Japan indicated, there appear to be relatively few in-person courses devoting attention to discussions of laboratory research with dual use potential, although, as the next section illustrates, interest and initiatives in these areas appear to be growing. There was also considerable discussion among the participants that a significant amount of information and training about responsible conduct and biosafety is currently provided informally, either through dedicated modules outside regular coursework or via in-laboratory mentoring by senior researchers. This may understate the amount of general education on these issues that is actually available to students, although participants generally agreed that it remains unclear if discussions of dual use were more widespread than the background surveys indicated. Rather, it emphasizes the need to consider other opportunities for providing education beyond formal coursework.

Although education specifically devoted to dual use appears to be minimal in many countries, the workshop participants supported the survey results that many universities have existing programs that address laboratory biosafety or which include an educational component on bioethics. They also introduced a theme that recurred throughout the workshop: The most appropriate settings in which to incorporate education on dual use issues may vary with educational level, institution, and country. Some participants noted, for example, that educational programs incorporating a strong ethics component appear to be more common in professional schools (e.g., medical, veterinary, and public health) than in basic life science programs. Other participants felt that ethics courses and modules were more common in graduate curricula than at other levels (undergraduate, postdoctoral researcher, or faculty). On the other hand, the survey data from Japan revealed the prevalence of bioethics courses at the undergraduate level (Minehata and Shinomiya 2009).

Findings

Based on the material in the background papers, other information collected by the committee, and the presentations and discussions in the

Warsaw workshop, the committee agreed on several findings about current conditions:

- **Available evidence suggests that, to date, there has been very limited introduction of education about dual use issues, either as stand-alone courses or as parts of other courses. Furthermore, few of the established courses appear to incorporate the successful practices and lessons learned from research on the "science of learning."**
- **Because a significant amount of information and training about responsible conduct and biosafety is provided informally, either through dedicated modules outside regular coursework or in-laboratory mentoring by senior researchers, currently available evidence may understate the amount of education on these general issues that is actually available to students. It remains unclear whether discussions of dual use may be more widespread than the background surveys indicated.**
- **A number of online resources for education about dual use issues are available, both for use by individuals and as the basis for or as supplements to courses. Only a few of the resources are explicitly designed to support active and engaged learning.**

BEYOND THE BASELINE: SOME EXAMPLES OF INCREASING INTEREST IN EDUCATION ABOUT DUAL USE ISSUES

The information available to the committee shows the limited extent to which dual use issues are part of current education for life scientists. The committee also found evidence, however, of a recent increase in examples of lectures, or modules, and entire courses addressing dual use issues. The changes were apparent, for example, between the discussions at the Second International Forum on Biosecurity in early spring 2008 (NRC 2009f) and the workshop in Warsaw in November 2009. The examples are an encouraging sign, in particular because they are occurring in many parts of the world. This section describes some of the efforts that emerged during the Warsaw workshop, as well as those reported elsewhere.

It should be noted that a significant number of the examples of new educational efforts represent the result of the work of the group associated with the Bradford Disarmament Research Centre mentioned above. In addition to the work already described, Malcolm Dando and Brian Rappert carried out more than 130 seminars and discussions for some 2,500 life sciences faculty at universities and research institutes in 15 countries. Although the primary purpose of the seminars was to gauge awareness of dual use issues, ascertain attitudes about potential oversight mechanisms, and raise awareness of the potential misuse of the life sciences for bioweapons development (Rappert 2008), the continuing contacts in a number of countries helped to support introduction of new educational material. Australia (Enemark 2010), Switzerland (Garraux 2010), and Sweden (Smallwood 20009) are among the examples, and in all these cases, as well as in Israel (Friedman 2010), there was some engagement by the government officials in helping to encourage the seminars or the follow-up activities.

As described above, the Education Module Resource was the result of collaboration with the Japan Defence Medical College and the Landau Network Centro Volta. Students at the Medical College receive different parts of the material at several points in their education as their needs and interests develop (Yamada 2009); additional material about the Japanese case may be found in Minehata and Shinomiya (2010). In addition, in cooperation with the Landau Network, implementation "tests" of the EMR were carried out in several countries, usually by providing one or more lectures as part of a regular course or workshop, with an evaluation afterwards (Mancini and Revill 2009:12). For example, in 2009, cooperation with the National Board of Biologists in Italian Universities, which coordinates a range of activities within Italy and between Italian and other European universities, enabled tests of parts of the EMR at the universities of Milan and Torino.

> Feedback from students suggests that 50% of students wanted further teaching on issues of misuse and the programme was most effective with small groups where students could be more actively engaged. In the future the biosecurity modules are to be developed and applied to other science courses within the university. (Smallwood 2009:7)

More such tests were planned for the future.

Other examples of new educational initiatives about dual use issues include the introduction of material from the EMR into syllabi in the master's program in biomolecular engineering course at Uppsala University in Sweden, with two 45-minute lectures into ethics courses. A less encouraging case that developed as part of the Bradford efforts is the continuing and so far unsuccessful effort to introduce a module on dual use and biosecurity into the curriculum in South Africa. This change would require a formal endorsement from the government that so far has not been forthcoming (NSABB and World Health Organization [WHO] 2009:18-20).

Universities in Australia have undertaken a number of activities related to dual use issues and biosecurity more broadly. As Professor

Seamus Miller reported at the Third International Roundtable of the NSABB and the World Health Organization (WHO), a National Centre for Biosecurity, a joint venture of the Australian National University and Sydney University, was established in September 2008 with support from the Australian government. The focus of the center is "research and education on all matters relating to biosecurity, including but not restricted to DUR [dual use research] issues. In addition, other activities are under way at centers that are connected with the National Centre for Biosecurity" (NSABB and WHO 2009:23).[12]

An example from the United States illustrates the use of the mandatory education to introduce dual use issues. In one of the cases cited in the AAAS survey, Professor Michael Imperiale of the University of Michigan lectures on research with dual use potential within the NIH-mandated RCR framework. The students

> watch a podcast of a past lecture and participate in small group discussion during class. In these small groups, students discuss the definition of dual use research, risks and benefits of conducting and communicating research, and the global nature of science and emerging technologies. Professor Imperiale also encourages his students to discuss the dual use dilemma with their colleagues. (AAAS 2008:13)

An example of including dual use issues in the bioethics curriculum is the work of Professor David Koepsell of the Delft University of Technology. In 2009 he used one of his own articles to introduce students to a basic ethical problem in research, focusing on the examples of smallpox and the mousepox case. The cases allowed the students to move from an introduction to basic ethical theory to exercises in ethical reasoning that he considers fundamental to all applied ethics (Koepsell 2009).

Dual use and biosecurity issues are also being introduced into some training and education on biosafety, which traditionally has been treated as primarily related to the skills needed for safe laboratory practices. Biosafety training also extends well beyond universities to include industry, government laboratories, and other research institutions. As discussed earlier, in recent years some have argued that biosafety can be a vehicle for fostering a broader "culture of responsibility" among scientists and that beginning with biosafety may also be the best approach in countries already seeking to bring their laboratories up to global standards (NRC 2009f). Linking laboratory biosafety with security measures can thus provide a context for introducing dual use issues as part of a larger context of responsible research.

[12] A fuller account of the Australian experience may be found in Enemark (2010).

The discussions during the workshop and in various reports offer a number of examples that suggest the linkages between biosafety and biosecurity—and hence opportunities for addressing dual use issues—are increasing; further information may be found in Chapter 4. With regard to biosafety and biosecurity in academia, in Pakistan, for example, efforts to develop a standardized curriculum on laboratory biosafety and biosecurity for undergraduate and graduate students in the life sciences are under way. This is part of the larger mandate of the National Core Group in Life Sciences to improve the quality of education and research in the life sciences in Pakistan.[13] A workshop participant, Dr. Anwar Nassim, Science Adviser at the Committee on Science and Technology Cooperation (COMSTECH), is the leader of this effort. The core of the proposed biosafety and biosecurity curriculum would be a two semester series, each lasting three hours a week for 15 weeks. The proposed curriculum includes relevant national and international guidelines and regulations, risk assessment, appropriate laboratory practices, and laboratory risk management. An optional third semester on special topics would also be available.

Findings

The committee found, based on these examples and others discussed at the workshop, as well as the results of other meetings and studies, that:

- **There is some evidence of an increase in the introduction of dual use issues into education in the life sciences. These examples come from all over the world and seem to result primarily from the work of an interested, committed individual or a specific project, often by a nongovernmental organization.**
- **At present, most of the examples of education about dual use issues occur as part of more general education about responsible conduct of research, in basic life sciences courses, as part of biosafety training, or within bioethics. In the United States, this extends to the specific education on responsible conduct of research (RCR) that is mandated by the National Institutes of Health and the National Science Foundation.**

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[13] Further information about the larger project may be found at http://ncgls.hec.gov.pk/.

REFERENCES

AAAS (American Association for the Advancement of Science). 2008. *Professional and Graduate-Level Programs on Dual Use Research and Biosecurity for Scientists Working in the Biological Sciences: Workshop Report*. Washington, DC: American Association for the Advancement of Science. Available at http://cstsp.aaas.org/files/AAAS_workshop_report_education_of_dual_use_life_science_research.pdf.

BWC. 2008. Report of the Meeting of States Parties. Geneva: United Nations.

Cello, J., A. V. Paul, and E. Wimmer. 2002. Chemical synthesis of poliovirus cDNA: Generation of infectious virus in the absence of natural template. *Science* 297(5583):1016-1018.

CEN (European Committee for Standardization). 2008. *International Laboratory Biorisk Management Standard.* CWA 15793. Brussels: CEN.

CDC (Centers for Disease Control and Prevention) and NIH (National Institutes of Health). 2007. *Biosafety in Microbiological and Biomedical Laboratories*, 5th ed. (L. C. Chosewood and D. E. Wilson, eds.). Washington, DC: U.S. Government Printing Office.

Enemark, C. 2010. Raising awareness among Australian life scientists. Pp. 131-148 in *Education and Ethics in the Life Sciences: Strengthening the Prohibition on Biological Weapons*. B. Rappert, ed., Canberra, Australia: Australian National University E Press.

FASEB (Federation of American Societies in Experimental Biology). 2009. Statement on Dual Use Research and Biosecurity Education. Bethesda, MD: FASEB. Available at http://www.faseb.org/Policy-and-Government-Affairs/Science-Policy-Issues/Homeland-Security-and-Visas.aspx.

Friedman, D. 2010. Israel. Pp.75-92 in *Education and Ethics in the Life Sciences: Strengthening the Prohibition on Biological Weapons*. B. Rappert, ed. Canberra, Australia: Australian National University E Press.

Garraux, F. 2010. Linking life sciences with disarmament in Switzerland. Pp.57-74 in *Education and Ethics in the Life Sciences: Strengthening the Prohibition on Biological Weapons*. B. Rappert, ed. Canberra, Australia: Australian National University E Press.

Hay, A. 2007. Multiple uses of chemicals: clear choices or dodgy deals? *Chemistry International* 29(6). Available at http://www.iupac.org/publications/ ci/2007/2906/pp2_2005-029-1-050.html.

IOM (Institute of Medicine). 1989. *The Responsible Conduct of Research in the Health Sciences*. Washington, DC: National Academy Press.

Israel Academy of Sciences and Humanities. 2008. *Biotechnological Research in an Age of Terrorism*. Jerusalem: Israel Academy of Sciences and Humanities.

Jackson, R. J., A. J. Ramsay, C. D. Christensen, S. Beaton, D. F. Hall, and I. A. Ramshaw. 2001. Expression of mouse interleukin-4 by a recombinant ectromelia virus suppresses cytolytic lymphocyte responses and overcomes genetic resistance to mousepox. *Journal of Virology* 7:1205–1210.

Koepsell, D. 2009. Biosecurity, Biosafety; Dual-Use Risks: Trends, Challenges and Innovative Solutions. Presentations to a Workshop. November 13-14. Como, Italy: Landau Network Centro Volta and Bradford Disarmament Research Centre.

Mancini, G., and J. Revill. 2009. *Promoting Sustainable Education and Awareness Raising on Biosecurity and Dual Use.* Como, Italy: Landau Network Centro Volta and Bradford Disarmament Research Centre.

Minehata, M., and D. Friedman. 2009. *Biosecurity Education in Israeli Research Universities: Survey Report*. Bradford, UK: Bradford Disarmament Research Centre and Institute for National Security Studies (Israel).

Minehata, M., and N. Shinomiya. 2009. *Dual-Use Education in Life-Science Degree Courses at Universities in Japan*. Bradford, UK: Bradford Disarmament Research Centre and Defence Medical College of Japan.

Minehata, M., and N. Shinomiya. 2010. Japan: Obstacles, lessons and future. Pp.93-114 in *Education and Ethics in the Life Sciences: Strengthening the Prohibition on Biological Weapons*. B. Rappert, ed. Canberra, Australia: Australian National University E Press.

NAE (National Academy of Engineering). 2009*. Ethics Education and Scientific and Engineering Research: What's Been Learned? What Should Be Done? Summary of a Workshop*. Washington, DC: National Academies Press.

NIH (National Institutes of Health). 2009. Update on the Requirement for Instruction in the Responsible Conduct of Research. NOT-OD-10-019**.** Available at http://grants.nih.gov/grants/guide/notice-files/NOT-OD-10-019.html, accessed September 2, 2010.

NRC (National Research Council). 2009d. *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: National Academies Press.

NRC. 2009f. *2nd International Forum on Biosecurity: Report of an International Meeting, Budapest, Hungary, March 30-April 2, 2008*. Washington, DC: National Academies Press.

NRC. 2009g. *Research at the Intersection of the Physical and Life Sciences.* Washington, DC: National Academies Press.

NSABB (National Science Advisory Board for Biosecurity). 2008. Strategic Plan for Outreach and Education on Dual Use Issues. Available at http://oba.od.nih.gov/biosecurity/biosecurity_documents.html.

NSABB and WHO (World Health Organization). 2009. Sustaining Progress in the Life Sciences: Strategies for Managing Dual Use Research of Concern. 3rd International Roundtable. Bethesda, Maryland: National Science Advisory Board for Biosecurity. Available at http://oba.od.nih.gov/biosecurity/biosecurity_documents.html.

Rappert, B. 2008. The benefits, risks, and threats of biotechnology. *Science & Public Policy* 35(1):37-44.

Rappert, B., ed. 2010. *Education and Ethics in the Life Sciences: Strengthening the Prohibition of Biological Weapons*. Canberra, Australia: Australian National University E Press.

Revill, J. 2009. *Biosecurity and Bioethics Education: A Case Study of the UK Context*. Bradford, UK: Bradford Disarmament Research Centre.

Revill, J., and G. Mancini. 2008. *Investigation into the Biosecurity Content of European Life Science Degree Courses.* Como, Italy: Landau Network Centro Volta and Bradford Disarmament Research Centre.

Revill, J., G. Mancini, M. Minehata, and N. Shinomiya. 2009. *Biosecurity Education: Surveys from Europe and Japan*. Bradford, UK: Bradford Disarmament Research Centre.

Second World Conference on Research Integrity. 2010. Singapore Statement on Research Integrity. Available at http://www.singaporestatement.org/.

Selgelid, M. J. 2010. Ethics engagement of the dual-use dilemma: Progress and potential. Pp.23-34 in *Education and Ethics in the Life Sciences: Strengthening the Prohibition on Biological Weapons*. B. Rappert, ed. Canberra, Australia: Australian National University E Press.

Smallwood, K. 2009. *Biosecurity, Biosafety and Dual Use Risks: Trends, Challenges, and Innovative Solutions*. Report. Como, Italy: Landau Network Centro Volta and Bradford Disarmament Research Centre.

Sture, J., and M. Minehata. In press. Dual-use education for life scientists: Mapping the current global landscape and developments. Report of the Bradford meeting, July 2010. Bradford, UK: Bradford Disarmament Research Centre.

Taubenberger, J. K., A. H. Reid, R. M. Lourens, R. Wang, G. Jin, and T. G. Fanning. 2005. Characterization of the 1918 influenza virus polymerase genes. *Nature* 437:889-893.

Tumpey, T. M., C. F. Basler, P. V. Aguilar, H. Zeng, A. Solórzano, D. E. Swayne, N. J. Cox, J. M. Katz, J. K. Taubenberger, P. Palese, and A. García-Sastre. 2005. Characterization of the reconstructed 1918 Spanish influenza pandemic virus. *Science* 310:77-80.

Vos, C. 2009. Background Paper for the International Workshop on Promoting Education on Dual-Use Issues in the Life Sciences: Online Dual-Use Education Materials. Available at http://dels-old.nas.edu/bls/warsaaw/edited_CJVos%20120November.pdf.

WHO (World Health Organization). 2004. *Laboratory Biosafety Manual*, 3rd ed. Geneva: World Health Organization. Available at http://www.who.int/csr/resources/publications/biosafety/ WHO_CDS_CSR_LYO_2004_11/en/.

WHO. 2006. *Biorisk Management: Laboratory Biosecurity Guidance.* Geneva: WHO.

Yamada, N. 2009. Dual-Use Bioethics Education Module Resource. Presentation on Panel "International Cooperation, Biosecurity and the Education of Life Scientists," Geneva: BWC States Parties Meeting.

Online Educational Materials

Bradford Disarmament Research Centre, National Defence Medical College of Japan, and Landau Network Centro Volta. 2010. Educational Module Resource. Available at http://www.dual-usebioethics.net, accessed August 3, 2010.

Center for Arms Control and Non-Proliferation. 2010. Biosecurity: Risks, Responses and Responsibilities. Available at http://www.armscontrolcenter.org/policy/biochem/biosecurity_educational_materials, accessed August 3, 2010.

Federation of American Scientists. 2010. Case Studies in Dual-Use Biological Research. Available at http://www.fas.org/biosecurity/education/dualuse/, accessed August 3, 2010.

Nuclear Threat Initiative. 2010. BW Terrorism Tutorial. Available at http://www.nti.org/h_learnmore/bwtutorial/index.html, accessed August 3, 2010.

Southeast Regional Center of Excellence for Emerging Infections and Biodefense (SERCEB). 2010. Dual Use Dilemma in Biological Research. Available at http://www.serceb.org/dualuse.htm, accessed August 3, 2010.

Stockholm International Peace Research Institute, Vrije Universiteit Brussel (Free University Brussels), and International Relations and Security Network. 2010. Educational Module on Chemical & Biological Weapons Nonproliferation. Available at http://poli.vub.ac.be/cbw/index.html, accessed August 3, 2010.

Student Pugwash USA. 2010. Biology and Security. Available at http://www.spusa.org/pubs/peace_security/biosecurity/index.html, accessed August 3, 2010.

University of Exeter, University of Bradford, and University of Texas at Dallas. 2010. The Life Sciences, Biosecurity and Dual Use Research: Dual Use Role Playing Simulation. Available at http://projects.exeter.ac.uk/codesofconduct/BiosecuritySeminar/Education/index.htm, accessed August 3, 2010.

4

Gaps, Needs, and Potential Remedies

INTRODUCTION

The remainder of the committee's charge was to:

- Identify gaps [based on its review of currently available courses and materials];
- Consider ideas for filling the gaps, and
- Discuss approaches for including education on dual use issues in the training of life scientists.

This chapter addresses these elements of the charge, drawing heavily on the information gathered and suggestions made during the workshop in Warsaw, supplemented by the growing number of other projects, reports, and meetings that have addressed education about dual use issues. Much of the discussion in Warsaw took place in breakout sessions, with additional information provided in plenary presentations and subsequent discussions. One of the plenary sessions on the first day and the first breakout session focused on providing additional information about the current state of education and the availability of online materials to supplement the background papers commissioned for the workshop; the results of these discussions were presented in the previous chapter. The remaining breakout sessions focused on specific topics, with the first four groups listed below addressing one set of common questions and the other four groups addressing a second common set. (The list of questions for all the sessions may be found in Appendix D.)

1. Approaches to engaged teaching and learning (seminars, simulations and role playing, interactive online approaches, etc.)
2. Teaching materials and curriculum content (topics, types of materials, resources for faculty, etc.)
3. Motivating "students" (policy and ethical issues useful for raising awareness and engaging scientists in dual use problems)
4. Preparing teachers (train-the-trainer, summer institutes, networks, etc.)
5. Including dual use issues in existing education/training programs (bioethics, biosafety, responsible conduct of research [RCR])
6. Developing models to foster and support education/training (centers of excellence, regional networks, virtual networks, clearinghouses)
7. Promoting and sustaining dual use issues by scientific organizations (scientific societies, scientific unions, academies of science)
8. Engaging the scientific community in dual use education (engaging faculty and institutional leadership)

In practice, there was considerable overlap and continuity within and across the sessions in Warsaw. For this reason, the rest of this chapter is divided into sections that address three broad topics, and the ideas from any plenary or breakout session may appear under one or more of these headings. The three sections are:

- *Educational Materials and Methods*, with "materials" defined broadly to include a variety of online resources;
- *Implementing Education About Dual Use Issues: Practical Considerations,* including teacher/faculty development, implementation at different stages of education and via existing programs such as bioethics or biosafety, and assessment and evaluation; and
- *Broader Implementation Issues*, such as financial resources and the roles of scientific organizations, governments, and international organizations.

Some of the sections begin with "Background" that offers an introduction or information from other sources. This depends on how much material may have been presented earlier, such as the discussion of active learning and effective teaching in Chapter 2. That is followed by summaries of the presentations and discussions that took place in Warsaw, in some cases with additional information from other sources. Each section ends with the committee's conclusions; the committee's recommendations are presented at the end of the chapter.

EDUCATIONAL MATERIALS AND METHODS

Background

The discussions during the workshop made clear that, beyond the available online resources identified in Chapter 3, additional educational materials and resources are needed if discussions of dual use research are to be incorporated more widely and effectively into education programs for life scientists around the world. Participants at the workshop addressed questions on the suggested content of these materials, the types of teaching methods that would be effective in presenting them, and the opportunities for developing materials more collaboratively and disseminating them more widely. One of the recurring themes in the discussion was that "no one size fits all," given the diversity of fields, interests, and experiences across the life sciences. The key is making the issue relevant to students and this requires a tailored approach. At the same time, participants also stressed the importance of finding ways to share successful practices and lessons learned as education about dual use issues expands.

Content

Participants suggested that content—to the greatest extent possible—be designed to complement a student's courses or be related to the scientific research being conducted in the researcher's laboratory. In this way, dual use issues would be seen as more directly relevant to the student and could be integrated into broader training programs rather than presented solely as stand-alone information. This also highlighted one of the most significant gaps identified by the participants: how much of the currently available online resources on dual use issues appear to be targeted to the U.S. research community. The materials frequently reference U.S. responses to events such as the 2001 anthrax letters, the establishment of bodies such as the U.S. National Science Advisory Board on Biosecurity (NSABB), and legislation such as the USA PATRIOT Act. Selected online materials have been produced by organizations in the United Kingdom and Western Europe, but the case studies presented to illustrate research with dual use potential are drawn primarily from examples conducted in laboratories in the United States and other developed countries, such as Australia. Implementing education about dual use issues on a global basis will require developing materials that speak more directly to students and faculty in other parts of the world.

With respect to such materials, some participants who had developed educational content on biosecurity and dual use research shared their experiences about which topics were most successfully received. Examples of real research cases, as well as fictional scenarios reflecting situations that students might conceivably face, were cited as effective in engaging at least some groups of students. Some students also responded to discussions of how life scientists, as individuals or through their professional associations, had responded to other important issues affecting the conduct of life sciences research. Changes in the treatment of human subjects and laboratory animals were mentioned, along with more general discussions of the changes in biosafety standards and practices that reflect increased awareness of potential impacts on laboratory workers or the broader environment. Participants expressed the belief that these kinds of cases could be made relevant across a wide variety of national contexts.

Some participants also discussed the use of more specifically security-related cases, such as the history of previous state bioweapons programs and the types of biological weapons that had been developed, as well as cases of bioterrorism or attempts at bioterrorism, such as those by Aum Shinrikyo. Some students found the discussions of the role of scientists in these past cases, and why they were involved, to be useful. The examples were most successful when used as part of discussions of how biosecurity issues were relevant to the students, and with a clear articulation of why students need to be aware of dual use issues. Some also reported that students were interested in the existence of the Biological and Toxin Weapons Convention (BWC) as an example of an international agreement dedicated to issues related to their studies or as the legal embodiment of the norm against the use of disease as weapon. Fewer students appeared interested in formal legal and regulatory structures (Smallwood 2009). Other participants suggested that discussions of biosecurity and research with dual use potential could be introduced to students by presenting potential security issues along a spectrum of risks that included natural and reemerging disease outbreaks as well as accidental releases and deliberate misuse.

Making Materials Accessible: The Language Barrier

One of the gaps most frequently cited by workshop participants was the lack of materials in languages other than English. This was part of a larger discussion during the workshop about the need to find ways to make both existing and new resources more widely and readily available. Some efforts are being made to translate the available materials; a few of the online case studies developed by the Federation of American Scientists (http://www.fas.org/programs/bio/educationportal.html, accessed July 10, 2010), for example, are available in French and Chinese, and the Education Module Resource (http://www.dual-usebioethics.net/, accessed July 10, 2010) from the Bradford Disarmament Research Center and its collaborators, has been translated into Japanese and Russian. Participants stressed that it could not be assumed that English proficiency would be common at the undergraduate level or in technical training settings such as biosafety that included a range of laboratory personnel. Even at the postgraduate level and beyond, where English could be considered "the language of science," those taking part in discussions of topics related to responsible conduct, ethics, and dual use might be more comfortable expressing complicated, controversial, or nuanced views in their native languages.[1]

Facilitating Collaborative Development and Making Materials Widely Available

A number of participants argued that the process of developing materials and teaching strategies for dual use education would benefit greatly from a collaborative approach and spirit. There is an opportunity to coordinate, and cooperate where possible, to save effort and resources while still tailoring particular activities to address specific fields, levels of education, and local or national context. One option that attracted substantial interest was the idea of a resource center or clearinghouse that could become an open-access repository to make curriculum and teaching materials widely available. Participants expressed the hope that such a repository could do more than collect and make materials available. Given the growing online capacities for discussion and collaboration, there were suggestions that some materials might be developed cooperatively. And as discussed further below, some participants also suggested that such a center could provide a venue for vetting materials and sharing lessons learned and best practices.

Several potential approaches to building this capacity were discussed in the workshop, and participants suggested that, with some effort and coordination, they might complement one another. The first would be to embed dual use issues within the science community by creating such a resource through a major scientific organization. The Second International Forum on Biosecurity in 2008 had suggested that the IAP, the global network of academies of science, might be the appropriate home (NRC 2009f). At the workshop, some participants proposed including materials about dual use issues in the resources available from a number of online centers that already exist to promote better science education; see Box 4-1 for a list and brief description of some examples. This proposal would have the advantage of integrating the materials into the broader efforts to incorporate the lessons from research on learning and teaching. Some

[1] Participants also recognized that in laboratory settings with multinational personnel, English might be the most practical language to use.

BOX 4-1
Projects and Resources to Improve Science Education

MicrobeWorld

Established in 2003, MicrobeWorld is an interactive multimedia educational outreach initiative from the American Society for Microbiology (ASM) that promotes awareness and understanding of key microbiological issues to adult and youth audiences and showcases the significance of microbes in our lives. The various outreach methods feature the process of discovery, historical changes in research, and a variety of scientific careers in industry, academia, and government.
www.microbeworld.org

MERLOT

Multimedia Educational Resource for Learning and Online Teaching (MERLOT) is a free and open online community of resources designed primarily for faculty, staff and students of higher education from around the world to share their learning materials and pedagogy. MERLOT is a leading edge, user-centered collection of peer-reviewed higher-education online learning materials, catalogued by registered members and a set of faculty development support services. MERLOT's strategic goal is to improve the effectiveness of teaching and learning by increasing the quantity and quality of peer-reviewed online learning materials that can be easily incorporated into faculty-designed courses.
www.merlot.org

SENCER

Science Education for New Civic Engagements and Responsibilities (SENCER) was initiated in 2001 under the National Science Foundation's CCLI national dissemination track. Since then, SENCER has established and supported an ever-growing community of faculty, students, academic leaders, and others to improve undergraduate STEM (science, technology, engineering, and mathematics) education by connecting learning to critical civic questions. SENCER's goals are to: (1) get more students interested and engaged in learning in science, technology, engineering, and mathematics (STEM) courses, (2) help students connect STEM learning to their other studies, and (3) strengthen students' understanding of science and their capacity for responsible work and citizenship.
www.sencer.net

participants suggested that making the materials available on a *science* site rather than a *security* site might also make them more acceptable to the broader community of scientists who would be asked to incorporate them in their courses.

The second approach would be to incorporate the materials into sites intended to support teaching in the three main areas where participants

BEN

BiosciEdNet (BEN) Collaborative was established in 1999 by the American Association for the Advancement of Science (AAAS) with 11 other professional societies and coalitions. The BEN Collaborative mission is not only to provide seamless access to e-resources but to also serve as a catalyst for strengthening teaching and learning in the biological sciences. BEN resources have been reviewed by the individual societies for standards of quality and accuracy; the collaborative establishment of its metadata structure permits the user to easily conduct productive interdisciplinary searches across the diverse biological sciences topics.
www.biosciednet.org

PKAL

Project Kaleidoscope (PKAL) is one of the leading advocates in the United States for what works in building and sustaining strong undergraduate programs in the fields of science, technology, engineering, and mathematics (STEM). As an intelligence broker within the undergraduate STEM community, PKAL disseminates resources that advance the work of academic leaders tackling the challenging work of ensuring that the undergraduate STEM learning environment serves 21st century students, science, and society most effectively, efficiently, and creatively. PKAL themes include institutional transformation, human and physical infrastructure, the academic program, pedagogical tools, the national context, and twenty-first century student education.
www.pkal.org

BioQuest

The BioQUEST Curriculum Consortium (BQCC) is a community of scientists, teachers, and learners who are interested in supporting biology education that reflects realistic scientific practices. The efforts in science education build on a commitment to engaging learners in a full spectrum of biological inquiry from problem posing to problem solving and peer persuasion. Many of the projects involve coordinating faculty development workshops that focus on strategies for bringing realistic scientific experiences into their classrooms and collaboratively developing curriculum projects.
http://bioquest.org/

suggested dual use issues could be quite readily added to existing education and training: biosafety, bioethics, and RCR. This has already happened to some extent with the Resources for Research Ethics Education (www.research-ethics.net) site in the United States, and there is a website where one can follow the efforts of the European Science Foundation and others to expand RCR education internationally (http://www.esf.org/activities/

mo-fora/research-integrity.html). The Global Bioethics Observatory of the United Nations Educational, Scientific, and Cultural Organization (UNESCO) was mentioned as a potential site already well known to the global bioethics community. At present none of these sites—or any similar ones—is deeply engaged in education about dual use issues, but it seems important to add this approach to the mix of possible opportunities.[2]

The third possibility would be to make use of a site devoted to broader issues of biosecurity and include education issues as part of its portfolio. This is the approach being taken by the Virtual Biosecurity Center (VBC), a new project that was presented at the workshop in Warsaw. The VBC is a project of the Federation of American Scientists and several U.S. and international partners. The VBC is intended to be an integrated information hub that provides a "one stop shop" for biosecurity and public health preparedness information. In this regard, the VBC will serve as a hub to distribute products and information produced by other organizations, including academics, nongovernmental organizations (NGOs), and governments. It would not produce its own content and would not take positions on issues. The plan includes an online community resource that would provide the capacity for discussions among specialized groups that could also use it to collaborate on activities such as the development of materials. One issue raised was the capacity of the VBC to reach beyond the biosecurity community that will be its natural constituency to engage more traditional science and science education organizations, but the organizers have already made progress in that area by engaging several U.S. science organizations and the Organization for Economic Cooperation and Development (OECD) as participants.

In the same vein, participants suggested that in some cases it might be appropriate to develop resource centers on a regional basis, where there might be more common experiences and examples to share and where networks might develop more readily and naturally. Other participants noted that in some regions the level of political tension among countries would make this difficult to implement and could lead to parochial approaches that would not benefit from a broader discussion of lessons learned elsewhere. Others suggested that national or regional centers could also be connected via the Internet, offering the advantages of local "ownership" of educational resources without sacrificing the benefits of international contacts.

Each of these options has advantages and limitations, and no clear consensus emerged from the workshop or the committee about the most

[2] The World Health Organization (WHO) has addressed dual use issues and has recently revamped its approach to biosafety education, but at present it has no plans to become a general resource on biosafety education.

desirable choice. Instead, given the ability of websites to provide links to one another, the options were viewed as potentially compatible and that, although more complicated, collaboration among different types of sites could be the ideal outcome.

A number of participants noted that achieving these possibilities, although well within the reach of current technology and feasible given the communication and collaboration that have developed in recent years among important parts of these communities, would require resources to develop and sustain the efforts. Participants cited numerous examples of worthwhile projects that had begun and then expired because of lack of continuing financial support.

Participants also noted the desirability of creating ways to vet the materials available for teaching about dual use issues and expressed interest in creating ways to share impressions and perhaps conduct more structured assessments. There was some discussion of a Wikipedia-style discussion and collaboration mechanism to develop materials, although this format requires careful monitoring to ensure that the material is factual. The technology to support a variety of online discussions is available; for example, it is to be a feature of the VBC. Again, participants pointed out that access to these online mechanisms varies and that these issues would need to be considered in the design of any collaborative effort. But the hurdles were not seen as insurmountable, and there was substantial enthusiasm for taking advantage of such approaches as another way to build and sustain a network of engaged educators.

Educational Strategies and Teaching Methods

Chapter 2 already provided an introduction to the research about the most effective approaches to teaching, so this section offers only a brief summary of some of the specific comments made during the workshop. Participants described and proposed a variety of possible approaches for informing students about dual use issues. It is important to note that these included more traditional lecture settings and the large classes typical in introductory courses, provided they included ample opportunities for interaction between students and teachers and small group discussions where possible.

In terms of active learning approaches, using either real cases or scenarios as part of role playing was cited as an effective method to deliver content, since it engaged students in experiencing the perspectives of different stakeholders. A number of participants also discussed ways to incorporate newer media, such as audio and video podcasts and YouTube, and virtual reality settings such as Second Life.

A range of online approaches were discussed, including both those that engaged students with teachers and with each other, and those that were intended for use by individuals. Some participants described ways to bring Web 2.0 resources, such as wikis and blogs, into an educational setting, given that students in at least some parts of the world experience them as a regular part of their lives outside the classroom.[3] For online groups, there was some discussion about generational differences, with younger students frequently seeming more engaged and comfortable with online discussions than older students (and perhaps faculty). For individually oriented online materials, the discussions underscored the need to avoid the passive go-through-a-series of slides, take-a-quiz, and print-a-certificate approach that characterizes a significant portion of traditional biosafety or RCR education.

For a number of participants, an overriding concern about the enthusiasm for online approaches was that the use of online teaching materials required sufficient connection speed and technical support, which may be a major limitation in reaching students where access to Internet is not universal. Participants stressed that, although this is frequently presented as a problem for developing countries, it also affects developed countries such as the United States where broadband capacity varies significantly. Several participants suggested that well-designed CDs or DVDs, which would not pose the same connectivity issues, could be used instead and could provide most of the same opportunities for engagement and interaction.

No single approach was considered the most appropriate or effective, and participants in several breakout sessions emphasized that more than one mode could be combined. Participants stressed again that the most effective teaching strategies were likely to depend on the targeted audiences.

Conclusions

Based on its understanding of the materials currently available, as described in Chapter 3 and above, on the additional material about teaching strategies in Chapter 2, and on the discussions at the Warsaw meeting, the committee concluded that:

- **Additional materials are needed that will be relevant to diverse audiences in many parts of the world, as well as those at dif-**

[3] An account of research about such efforts at the K-12 level was presented at the 2010 conference of the International Society for Technology in Education and offers potentially relevant suggestions for more advanced settings. It may be found at http://center.uoregon.edu/ISTE/2010/program/search_results_details.php?sessionid=50054537&selection_id=54084303&rownumber=4&max=4&gopage=, accessed July 10, 2010.

ferent educational stages, in different fields within the life sciences, and in related research communities. A number of good resources have been developed, but there is a need for more that are relevant to research related, for example, to plants or animals and to fields that are not as obviously security-related.
- **More materials are needed in languages other than English. This will be particularly important in undergraduate settings or when used as part of technical training (i.e., biosafety).**
- **In addition to online resources, materials such as CDs or DVDs that can provide comparable opportunities for engaged learning are needed for areas that lack the sustained access or capacity to take full advantage of Web-based materials.**
- **Providing widespread access to materials that could be adapted for specific contexts or applications through open access repositories or resource centers would be important to implementing and sustaining dual use education.**
- **Given current technology, it would be feasible to create the capacity to develop materials through online collaborations, as part of or in partnership with repositories or resource centers. Online collaborative tools can be a key mechanism to facilitate global participation in the development of materials, although, again, issues of access to the Internet will need to be considered in designing any arrangements.**
- **Developing methods and capacity for the life sciences and educational communities to comment on and vet education materials, such as an appropriately monitored Wikipedia model, would be important. Another important capacity would be the ability to share lessons learned and best practices about materials and teaching strategies as experience with education about dual use issues expands. If appropriate resources are available, both this and the previous conclusion should be well within the capacity of current online technologies.**
- **Teaching strategies need to focus on active learning and clear learning objectives, while allowing for local adaptation and application.**

IMPLEMENTING EDUCATION ABOUT DUAL USE ISSUES: PRACTICAL CONSIDERATIONS

Opportunities to Implement Education in Varied Settings

A recurring theme during the workshop was the variety of settings in which content about dual use issues could be introduced. This discussion reflected the diversity of the participants and, as described in Chapter 3, the conditions in which education about dual use issues is currently taking place. Participants suggested that including dual use issues in general ethics discussions that cover a range of possible topics may provide a more general framework to reach a diverse potential audience, while including dual use in more specialized laboratory biosafety training may reach those researchers whose expertise and capabilities may be most directly relevant to preventing the nefarious use of life science knowledge. Workshop participants felt that both types of training offered fruitful paths to achieving the goal of responsible scientific conduct and that any opportunities to introduce the concept of dual use into ongoing educational discussions should be taken, whether this was through biosafety, bioethics, biosecurity, or other avenues. Some participants also suggested that the growing interest in expanding education about dual use issues, such as the proposal to require such education for all federally funded life scientists in the United States (NASBB 2007, Rocca 2008), might be a way to increase support for education about responsible conduct more generally.

Similarly, it was suggested that including discussions of potential dual use issues in multiple contexts and courses would help to reinforce the material. For example, references to case studies of research having potential dual use implications could be used during lectures on topical biological content such as DNA or protein synthesis. Many participants expressed the view that it would be essential to emphasize the positive potential of research, while linking to other topics in ways that can be engaging and perhaps provoke an emotional as well as an intellectual response. All of these comments again underscored the need to consider how to make cases relevant to the student's own experience or interests and to tailor approaches rather than simply taking materials off the shelf.

Several of the groups also considered the educational stages at which information on dual use issues in life sciences research could be presented. Many participants felt that dual use issues could be appropriately introduced to multiple potential audiences, including undergraduates, laboratory technicians, graduate students and postdoctoral fellows, and professionals and faculty members.[4] The materials targeted to these groups might have different teaching goals and be presented using different teaching methods, but they would provide exposure to responsible conduct of science concepts, such as dual use, at several different career

[4] There was also some discussion of introducing dual use issues with high school students, but it was not a focus for the workshop.

points. For example, it was suggested that undergraduate education provided an opportunity to reach a broader cross section of students, many of whom may not specialize in life sciences laboratory research but may go into related professional fields or may benefit from becoming part of a more informed public. In this regard, the SENCER project described in Box 4-1, which develops case study materials for active learning focused on how science and engineering is important to key societal issues, could be a model. Karen Oates, a longtime participant in the SENCER project suggested that dual use issues fit well within the type of problems that the case studies used to engage students.

At this stage, it was suggested that it was helpful to introduce ethical discussions by emphasizing the positive benefits and value of science. Several participants expressed serious concerns that emphasizing potential misuse could discourage individuals, especially younger students, from entering the field. Some participants felt that the issues might be more easily integrated into undergraduate education, before the pressures of increasing specialization and the demands of building a research career made it difficult to consider anything beyond one's immediate academic interests.

At graduate and more specialized levels, participants felt that education on potential dual use issues had the capacity for greater impact but, for the reasons just cited, might be more difficult to integrate. At these stages, the importance of mentors, the research laboratory environment, and incentives also become more significant. Support from senior faculty for the importance of a culture of responsibility and for considering broader societal issues, including dual use, was cited as very important in creating an environment in which students would feel encouraged and enabled to think beyond their particular research.

One participant proposed a possible approach for introducing dual use issues to undergraduate and graduate students that synthesized many of the ideas discussed:

- Introduce concepts in an incremental fashion as students become more advanced in their education and training.
- Begin with general training in good laboratory safety practices, including basic biosafety.
- Introduce ethical concepts more broadly, including discussions of the social responsibility of science and the role of science in society.
- Introduce more specialized information on biosecurity and dual use concepts later in the process. One possible introduction point could be when students begin to do their own research.

- Consider incorporating relevant examples of research demonstrating potential dual use implications as part of regular subject matter lectures.
- Consider opportunities to extend modestly the existing discussions of social, historical, environmental, and ethical aspects of science that occur in Advanced Placement (AP) biology or A-level high school courses, so that audiences receive additional information about the ethical implications of scientific research (such as the existence of potentially dual use research) before reaching a university.

The workshop participants also emphasized the importance of engaging multiple research communities when discussing education on dual use issues and the life sciences. In addition to basic and clinical scientists studying human pathogens, participants noted the importance of discussing these concepts with veterinary and agricultural researchers. Participants also noted that examples of research having potential dual use implications could be drawn from multiple areas of biology, not simply the highly dangerous pathogens that are the usual focus.[5] As a result, it was suggested that students and scientists across the spectrum of the life sciences could broadly benefit from an awareness of the fundamental ethical norms of science, the concept of research with dual use potential, and how this issue might be relevant to them. There could also be valuable lessons for the design and implementation of education to be learned from the experience of other disciplines in addressing issues of ethics and responsible conduct (NAE 2009). Modern biological research also engages collaborators in mathematics, computer science, engineering, materials chemistry, and other fields, and these partners may receive training as students in somewhat different subsets of ethical issues.

Finding ways to incorporate partner communities in a discussion of the potential needs and opportunities for education on dual use issues may also be beneficial. The synthetic biology community and programs such as the International Genetically Engineered Machine (iGEM) competition were noted as examples. Synthetic biology has garnered substantial recent attention, and members of the field have made conscious efforts to consider the potential social, ethical, and security implications of their current research and future plans (Garfinkel et al. 2007, Bügl et al. 2006). The student teams participating in the iGEM competition are now required to consider the potential security implications of their projects and synthetic

[5] See, for example, the report of a workshop at the Royal Society in 2006 for a discussion of research in a number of fields beyond those traditionally associated with biological weapons or bioterrorism, including immunology and neuroscience (Royal Society 2006).

biology more generally as part of the broader social implications of their work (see http://2010.igem.org/Security, accessed July 11, 2010).[6]

In addition to the array of life sciences and related research communities, the Warsaw workshop emphasized the importance of engaging education experts. Designing effective programs to discuss ethical issues in the life sciences, including implications of dual use research, requires not only decisions on the content to be taught but also on the process employed to teach and assess it. An important aspect of the Warsaw workshop was its effort to combine subject matter experts in biosecurity and biosafety, practicing life scientists, and people with expertise in effective teaching and learning strategies.

Strategies to Develop Faculty and Instructors

One of the major gaps cited consistently by participants was a lack of faculty and instructors able to provide education about dual use issues. This reflects the fact that at present relatively few professors are themselves aware of dual use issues, so increasing the number of faculty trained to teach about these issues would be necessary if education is to be expanded. Participants discussed strategies to fill the gap by engaging and supporting faculty or instructors, including the development and presentation of materials. Participants agreed that the most effective teachers are those who are expert, authentic, and enthusiastic about the material they are conveying. In addition to expanding training opportunities for faculty, participants suggested employing team-teaching methods or drawing on guest lecturers with specific expertise.

Participants also highlighted the possibility of identifying and supporting "champions" to carry initiatives forward, form connections, and engage additional interested participants. Some suggested identifying well-regarded faculty at important national or regional universities and bringing them into the proposed online networks created through resource centers and clearinghouses to facilitate "local" content and applications.

Participants heard about several models from biosafety, bioethics, and general science education that are in use or could be adapted to develop faculty and instructors. At the time of the Warsaw workshop,

[6] The website contains a box suggesting that "as a participant in iGEM, there are three things you can do right now to help us secure our science:

- Include something in your project description and presentations that demonstrates that you have thought about how others could misuse your work
- Contribute to community discussions on what needs to go into a code against the use of our science for hostile purposes (see A Community Response)
- Look into what security provisions, such as laws and regulations, are already in place in your country (see Working within the Law)."

Pamela Lupton-Bowers was in the process of revamping the train-the-trainer program at the World Health Organization to align with the new focus on biorisk management that includes both biosafety and laboratory biosecurity (WHO 2006; see also discussion in Chapter 1). The traditional program—described by another participant as "death by PowerPoint"—has now been redesigned. The new program reflects concepts

> based on the latest science and theory behind accelerated and adult learning. This highly interactive workshop builds the knowledge and skills of individuals who train and educate others in the biorisk management community. The workshop is intended to increase the number of qualified trainers able to support biorisk management globally (WHO 2010).

Participants in the workshop were expected to have some prior teaching/training experience and to be prepared to carry out at least two training sessions a year in their regions or countries. The first seminar was held in Amman, Jordan, in April 2010, and five more were planned throughout 2010 to reach all six of the WHO regions.

Another approach to faculty development has been created by Simon Whitby of the University of Bradford as part of the broader project on "Dual Use Bioethics" that includes the Education Module Resource described in Chapter 3. (An overview of the project may be found at its website: http://www.dual-usebioethics.net/, accessed July 11, 2010). This train-the-trainer program will take advantage of distance learning techniques and advanced videoconferencing capabilities at the University of Bradford to take relatively small groups of faculty through a series of lectures based on the EMR as well as a set of interactive scenarios designed to explore ethical dilemmas related to dual use research.

> Working in a fully supported online learning community, participants will be able to communicate and interact with peers, developing their practice through sustained reflection and participation in a range of activities and scenarios. Participants will be encouraged to bring their own personal ideas and experiences to the course, sharing these with peers in order to contextualise their knowledge and understanding in ways that will help them meet the ethical challenges thrown up by dual-use (Bradford Disarmament Research Centre website 2010).

The project carried out its first short course in the fall of 2010.

A third approach is being undertaken as a follow-up to the Warsaw workshop by the National Research Council of the U.S. National Academy of Sciences with support from the Biosecurity Engagement Program of the Department of State. The project will adapt a model developed to promote new, more effective methods of teaching in undergraduate biology. As described in Chapter 2, the Summer Institutes on Undergraduate Education in Biology (http://www.AcademiesSummerInstitute.org/, accessed July 11, 2010) have helped to train over 250 faculty members in effective methods of teaching, reaching over 100,000 students per year. The Summer Institutes bring approximately 40 life sciences faculty members together for a week devoted to learning about effective methods of teaching and developing innovative curricular materials that participants implement in their own classes in the following academic year. The Summer Institutes also seek to develop a sense of community among the participants and build a network of life sciences faculty devoted to high quality life sciences education (Pfund et al. 2009). The first step in the new project will be a small planning meeting in late 2010 or early 2011. The meeting will have two tasks: (1) to work on a general model for how such programs could be applied to education about dual use issues and adapted for different international contexts and (2) to design a first pilot-test institute. The first institute would be held in the Middle East/North Africa on the campus of a regional university or center with a strong commitment to improving science education. The project is seen as an opportunity to support education about dual use issues within the broader context of new methods of science teaching and general responsible conduct of research recommended in this report.

For all the approaches participants stressed the importance of including plans for post-training support, both for developing and implementing new methods and materials and for sharing lessons learned and best practices. It is worth noting that some models, such as the Summer Institutes, deliberately include small teams rather than single individuals from a given institution in order to enhance the chances of sustaining what is learned and a commitment to implementation is part of the selection process. The champions cited earlier in this section may also help to create and sustain a more hospitable climate for new content and methods. In addition to supporting work at home institutions, some models for building networks of faculty and instructors also bring graduates together after their training for special follow-up activities to reinforce what was learned, while others rely on the normal cycle of meetings that take place in a discipline or professional field to provide convening opportunities.

In keeping with the theme that different approaches will be effective in different situations, the workshop and the committee did not seek to identify a preferred approach. Promoting multiple channels for education about dual use issues seems most likely to reach the greatest variety of life scientists and produce the materials and methods most appropriate to particular settings.

Assessment and Evaluation of Courses and Materials

The workshop participants recognized that the success of educational materials and programs also have to be assessed to determine their impact and allow improvements to be made to their effectiveness. As discussed in Chapter 2, courses and materials need to be designed with the objectives and teaching goals clearly identified at the outset, followed by the selection of the most appropriate content and other details. This represents both good pedagogy and facilitates the assessment process.[7] Some participants also commented that, with education about dual use issues at such an early stage, this was the time to begin thinking about assessment and evaluation, so that appropriate strategies and methods could be included from the beginning rather than after the fact. The current efforts to survey the availability of courses and modules also provided a useful if admittedly imperfect baseline against which to measure at least the basic objective of expanding the number and range of dual use education being offered.

There was not a clear consensus about the effectiveness of various assessment methods, and participants recognized that it remains difficult to measure changes in concepts such as "awareness" or even more difficult to demonstrate that any given education program has met the ultimate goal of preventing proliferation or terrorism. There was also concern that the current pressure for "metrics" from some private and government funding sources sometimes led to assessments focused on what could be readily measured rather than what truly mattered. A particular concern was the need to distinguish between collecting data on *outputs*, such as the number of students who took a course, and the more challenging measures of *outcomes* that largely relate to the issues discussed in Chapter 2 and of the even more elusive *impacts* that relate to the policy and other goals that the education seeks to achieve. Each is appropriate for certain purposes, but there was a recognition that only measuring outputs would not provide a meaningful assessment of whether the education is actually enhancing the culture of responsibility in the life sciences. There was also some concern that assessment not become so intrusive or burdensome that it would discourage either students or faculty from undertaking the new approaches and content.

In spite of the challenges associated with assessment of educational programs about life sciences research with dual use potential, participants felt that assessment would be feasible and could draw on some of the

[7] An introduction to the enormous literature on program evaluation may be found in Wholey, Hatry, and Newcomer (2004). For a discussion of assessing learning outcomes, see NRC 2003b.

standard types of assessment instruments. As discussed in Chapter 2, suggested approaches to assessing students included:

- Assessing factual knowledge with examination questions.
- Using surveys of individuals to establish a baseline for monitoring and assessment. For example, surveys before and after a course/module can document immediate changes in awareness and views. Surveys could also be designed to provide longer-term feedback.
- Assessing more abstract/broader goals of engagement and substantive reasoning with tutorials, group work, and essays.

Participants also suggested approaches for measuring the broader goal of expanding education about dual use issues that included:

- Using surveys of the sort discussed in Chapter 3 to establish a baseline and then monitoring changes over time in areas such as:
  - —How many syllabi are including the topics
  - —How many textbooks make references
  - —How many publications deal with the topics
  - —How many modules or portions of courses are devoted to the topics
  - —How many hits and downloads of various online resources
- Monitoring changes in policy over time that could result from in-depth training at a variety of levels, although the causal connections may be hard to establish. This could include, for example, both adding and adapting a country's regulations, grant processes, or educational policies and avoiding changes that would negatively affect science without adding to security.
- Measuring awareness and understanding among the public and policy makers as a complement to assessments focused on the life sciences community.

Barriers to Implementation

The participants discussed a range of obstacles to implementing education about dual use issues. Perhaps the most serious, participants agreed, is the continued lack of awareness among practicing scientists about the concept of dual use or about the potential issues posed by research in the life sciences with dual use potential. Ironically, the fundamental purpose of education is to raise awareness and foster norms of responsible conduct, but until that happens, limited awareness frequently translates into limited support for including dual use issues in the curriculum. Some participants suggested that there was a particular gap between developing and industrialized countries and that an awareness of dual use concerns seemed to correlate with the amount of life sciences research being conducted in a given country. Discussion group members also noted that, even where scientists were aware of the concept of research with dual use potential, many did not necessarily feel that the issue was relevant to them or posed risks with which they should be concerned.

In addition to the continuing problems posed by a lack of awareness, the participants discussed a number of other barriers that face any efforts to change the basic curriculum in the life sciences or to improve the way that science is taught. Each can be a serious obstacle and taken together they pose formidable challenges to expanding education about dual use issues. These barriers include, for example:

- A crowded curriculum that makes it difficult to add new or additional material. This is a common problem in efforts to introduce education about responsible conduct, and it also affects efforts to expand the training that life scientists receive about other, increasingly relevant disciplines, such as physical sciences or mathematics and computer sciences. Dual use issues may find it hard to compete in what can seem a zero-sum battle for space in the curriculum.
- Participants argued that, although the situation has changed in settings that have embraced inquiry-based learning approaches to science education, there still remain others where teaching is not highly valued among faculty members, especially at universities with a strong emphasis on research. In such cases, there may be few rewards for teaching and few incentives for faculty members to devote themselves to acquiring the kinds of skills that would enable them to introduce active learning approaches in their classrooms.
- Students often feel pressure to focus on their research, especially as they move farther along into graduate study. Senior faculty and laboratory directors frequently convey this message, either directly or by suggestion, making it harder for students who might like to explore other ideas. A bad job market may compound the sense that anything beyond one's immediate research is a distraction.

Another significant barrier that participants discussed was the variation in how new courses or modules are introduced into the curriculum. The process varies widely, from the very informal, in which a faculty member might need to do no more than gain permission from his or her department chair, through increasingly hierarchical structures that prescribe specific courses and even course content and may require approval at the highest levels of government to change. One participant, for example, stated that he would need formal permission from the Ministry of

Education in his country to introduce dual use issues. Participants saw this variety as further reinforcing the need to take approaches to education that could recognize and adapt to local and national contexts.

Conclusions

Based on its understanding of the courses and materials currently available, as described in Chapter 3, on additional material cited above and in Chapter 2, and on the discussions at the Warsaw meeting, the committee concluded that:

- **Incorporating education about dual use issues into the channels through which life scientists already receive their exposure to issues of responsible conduct—biosafety, bioethics and research ethics, and RCR—offers the greatest opportunity to reach the largest and most diverse range of students and professionals. Biosafety training reaches those with the most capabilities, knowledge, and motivation relevant to dual use. In addition, biosafety may be of particular interest for developing countries that are attempting to raise their overall standards of laboratory practices. Ethics and RCR are more general and may reach more people. The available evidence suggests that the use of multiple channels is already the most common approach.**
- **If the approach above is taken, then growing interest in expanding education about dual use issues, such as a proposal being considered within the U.S. Government to require such education for all federally funded life scientists, might also be an opportunity to expand more general education about responsible conduct.**
- **It will be important to reach out to other disciplines that are increasingly part of life sciences research—physical sciences, mathematics, and engineering—as part of education about dual use issues. There may also be useful ideas and lessons from how these fields provide education about ethical issues and the potential for misuse of scientific results.**
- **Training opportunities to help faculty develop the skills, abilities and knowledge needed to teach dual use issues effectively are essential if education about dual use issues is to expand successfully.**
- **There are several promising models for "train-the-trainer" programs on which to draw, but a common characteristic is the use of the experience to create a network among faculty members to support and sustain each other and to encourage expanded education.**

- **It is important to consider appropriate approaches to assessment and evaluation of education about dual use issues early in the process of developing and implementing new courses and modules.**
- **In addition to a lack of awareness of and engagement in dual use issues among life scientists, there are a number of obstacles to any effort to implement new content or teaching methods, such as competition for space in crowded curricula, pressures on students to focus on their research, and in some cases a general lack of support for teaching.**

BROADER IMPLEMENTATION ISSUES

Background

Questions related to education about dual use issues can be considered part of the larger discussions and activities that have been taking place in the international scientific community about biosecurity. For example, examination of the roles of academies, scientific unions, and professional associations or the roles of governments and international organizations cuts across many specific issues (see, for example, the discussions in *On Being a Scientist* [NRC 2009a]). This section addresses a number of such issues in the particular context of expanding education about dual use issues worldwide, with a focus on the roles of scientific organizations, governments, and international agreements and organizations. The committee recognizes that the infrastructure to support a broader culture of responsibility in the life sciences includes other important institutions, such as journal and textbook publishers, colleges and universities, research institutes, and the private sector. But these are the three that the committee wants to highlight in this report, because they were featured in the discussions during the workshop in Warsaw and because each currently has significant opportunities to play a role in expanding education about dual use issues. Before that discussion, however, the report considers the perennial question of resources, which also introduces the role of funding bodies.

Financial Resources

As in many other discussions about expanding education about dual use issues, the need for resources, especially financial, emerges almost immediately (see, for example, NRC 2009f, AAAS 2008, and BWC 2008). In many countries, university administrators and faculty, who normally live in dread of "unfunded mandates," are particularly stretched by the impact of the current financial crisis. It might not be particularly expensive for a newly enthusiastic professor to develop a few sessions about dual use issues for an existing course or as a special side event, but if dual use issues are to become a regular part of the curriculum across the life sciences, much more substantial and sustained funding would be required. Among the needs cited by participants were funds to:

- Develop new case studies and educational materials tailored to the research interests of scientists in different areas of the life sciences as well as to the interests and priorities of different countries.
- Translate relevant existing case studies and educational materials into local languages.
- Develop materials such as CDs or DVDs that could provide experiences similar to online interactions and engagement to those lacking reliable Internet access.
- Support the creation of clearinghouses or resource centers, which could be linked to form an international network, where materials could be deposited, shared, and developed and vetted collaboratively.
- Undertake meeting sessions, workshops, articles and other publicity to engage students and faculty through various scientific organizations and professional associations.

A common feature of many of these points is that implementation would require time for faculty and instructors (and in some cases administrators) to develop the new resources and programs. Underwriting time for similar purposes is a common practice for private and public funding bodies, suggesting a role that some are already playing.

Many participants acknowledged the important contribution that private funding, particularly from foundations in the United States and the United Kingdom, has made and continues to make in supporting the development and implementation of education about dual use issues. Much of the most creative work to engage the scientific community in biosecurity and dual use issues in the past decade has come as a result of the support of the Alfred P. Sloan Foundation, the Carnegie Corporation of New York, the Nuclear Threat Initiative, and the Wellcome Trust. But only the Wellcome Trust continues to support work on dual use issues; at present there are no major U.S. foundations with programs on dual use or broader biosecurity issues. And private organizations obviously cannot develop and implement the policies to support a greater role for education. Participants argued that national governments as well as regional and international organizations have essential roles in providing resources; this issue is discussed further below.

The Role of Scientific Organizations

The Warsaw meeting participants generally believed that scientific organizations could play valuable roles as partners in promoting and sustaining education about dual use issues, and could undertake mutually reinforcing activities to integrate education and awareness within the scientific community. One clear advantage is that scientific societies and other professional membership associations reach a significant base of working scientists in relevant areas of the life sciences. Their engagement provides authoritative and credible endorsement for the importance of addressing the challenges dual use issues pose. Such messages may also be more acceptable to scientists from such a source than from governments.

Participants acknowledged that capacity varied greatly among the organizations and that the splintering of the life sciences among many separate groups at the national and international level made the task of engaging "the life sciences community" more difficult. A number of these organizations are already active in biosecurity, however, as their roles as conveners of the workshop illustrated. Chapter 1 described some of the activities, and more detail is available in Appendix C.

These organizations operate at the national, regional, and international level, as well as serving particular scientific fields. Even if nationally based, the organizations may have a significant international membership. The American Society for Microbiology (ASM), for example, includes over 43,000 individual microbiologists, approximately 30 percent of whom are international members. Regional and international unions and other federations of multiple societies can serve wider geographical and disciplinary representation and may effectively play diplomatic roles in conveying broad messages to their national members. Materials produced by one society may also be distributed for adaptation and use by others via these federations. In this way, smaller members may benefit from existing resources generated by larger organizations. The International Union of Microbiological Societies (IUMS), for example, includes over 100 societies in 65 countries, of which ASM is one of the largest members. Similar unions exist in molecular biology (International Union of Biochemistry and Molecular Biology, IUBMB), chemistry (International Union of Pure and Applied Chemistry, IUPAC), and other related fields. The IUPAC *Multiple Uses of Chemicals* was described in Chapter 3, and as announced during the Warsaw workshop, the first IUMS regional course for graduate students and practicing professionals from developing countries, "Antimicrobial Resistance in Bacteria, Fungi and Viruses," held in Singapore in June 2010, included a short session on dual use issues led by Professor Geoffrey Smith, a member of the workshop organizing committee (http://iums.org/Outreach/index.html, accessed June 20, 2010).

As an umbrella international association linking multiple science academies, the IAP has also been influential in encouraging its members to address dual use issues through the efforts of its Biosecurity Working Group. Participants singled out the 2005 IAP Statement on Biosecurity (IAP 2005) as another useful resource to build local scientific engagement and commitment. In addition to IAP, other umbrella scientific organizations may be valuable partners in efforts to increase the extent to which social responsibility and ethics training are incorporated into the life sciences. The International Council for Science (ICSU), which includes both national academies of science and scientific unions as its members, also has a Committee on the Freedom and Responsibility of Science.

Workshop participants discussed other contributions that they believed scientific organizations could make to education and the ways to promote and sustain such engagement. Participants suggested making use of existing fora, such as scientific conferences, science education conferences, and other meetings to discuss dual use issues and foster engagement. Activities will need to be tailored to local and regional needs, and different approaches may be appropriate to engaging scientists in different countries. Participants thus envisioned a collection of activities at several scales, in which local and/or discipline-specific organizations might generate material relevant for their particular audiences, regional networking could be used to promote education about aspects of safety and security, particularly as linked to the development of standards and best practices, international activities and partners could lend support to local and regional activities, and workshops could be encouraged to share and disseminate materials and to build networks and capacity.

The potential of codes of conduct as education tools has already been mentioned, but it should be noted here that a number of professional societies and unions have codes of conduct that include biosecurity and dual use issues. ASM, for example, has long devoted attention to the ethical issues around biological weapons and more recently bioterrorism. Interestingly, it was participation in the 2005 BWC meetings related to codes of conduct that provided the impetus for IUMS and IUBMB to develop codes of ethics for their organizations and members.[8]

National academies of science can also draw on their convening power to organize meetings and may inform the policies of governments by providing advice through studies and reports or other advisory capacities. Warsaw participants highlighted the role of science academies as sources of advice for their governments and noted the value of scientific assessments conducted by academies in giving credibility to the impor-

[8] The IUMS code may be found at http://www.iums.org/about/Codeethics.html. The IUBMB code may be found at http://www.iubmb.org/index.php?id=155&0=.

tance of dual use issues in biology. This includes studies, such as the Fink and Lemon-Relman reports (so-called after the chairs of the committees that produced the reports, produced by the National Research Council of the U.S. National Academy of Sciences [NRC 2004a, 2006]), and reports from the Israel Academy of Sciences and Humanities (Israel Academy 2008) and the French Academy of Sciences (Korn, Berche, and Binder 2008). A number of academies have also conducted workshops or other convening activities, such as two regional meetings carried out by the Ugandan National Academy of Sciences (UNAS 2008, 2009) and a workshop by the Chinese Academy of Sciences in cooperation with the OECD in 2008. In 2006, The Royal Netherlands Academy of Arts and Sciences (KNAW) undertook to develop a code of conduct on biosecurity at the request of the Dutch Ministry of Education, Culture and Science. KNAW convened a Biosecurity Workgroup as well as a focus group of researchers and policymakers to provide input into the process. The code articulates guiding principles to inform responsible conduct. Of particular relevance to the question of education is the section on "Raising Awareness," which recommends in part to "devote specific attention in the education and further training of professionals in the life sciences to the risks of misuse of biological, biomedical, biotechnological and other life sciences research and the constraints imposed by the btwc [sic] and other regulations in that context" (KNAW 2007:11).[9] Following the release of the code in October 2007, the KNAW organized presentations and debates, and it continues to follow up on the dissemination activities. A list of a number of these activities involving academies and unions appears at the end of Appendix C.

Biosafety associations represent another important type of professional organization. The International Federation of Biosafety Associations, IFBA, provides the same umbrella function as ICSU and the scientific unions do for the disciplinary societies. Several countries have also recently established national biosafety councils and/or national biosafety associations or have begun to consider biosecurity issues within the framework of biosafety organizations. For example, Morocco recently created a National Commission for Biosafety and Biosecurity, and the country hosted the second Biosafety and Biosecurity International Conference (BBIC09) in April 2009 in partnership with the Environment Agency of Abu Dhabi and the Royal Scientific Society of Jordan.[10] The Brazilian Biosafety Association (ANBio) initiated biosecurity activities in 2007 and has organized several training courses for workers in BSL-2 and BSL-3

[9] The code may be found at http://www.knaw.nl/publicaties/pdf/20071092.pdf .

[10] Further information about the regional BBIC may be found at http://www.biosafetyandbiosecurity-2009.org/.

laboratories; a Latin America Laboratory Biosafety and Biosecurity Conference was held in May 2008. In the Philippines, the Department of Health initiated a National Laboratory Biosafety and Biosecurity Action Plan Task Force in 2006, and the Philippine Biosafety and Biosecurity Association was established in 2007. Its Inaugural Symposium on Advocacy and Awareness on Biosafety and Biosecurity was held in March 2009 in association with several Philippine government agencies and with the U.S. Department of State Biosecurity Engagement Program. The Pakistan Biological Safety Association was established in 2007 under the Pakistan Society for Microbiology and has organized several laboratory safety workshops. These efforts and organizations can provide alternative avenues, beyond university-level academic courses, to address training and education on the potential dual use of life sciences research.

The Role of Governments

Most of the emphasis in this report has been on the "bottom up" approach that so far characterizes most of the efforts to expand the attention given to dual use issues in life sciences education. Participants also discussed how important some forms of "top down" support from governments would be to complement and help sustain the "bottom up" activities and initiatives. Perhaps the most obvious role, given the many needs identified during the course of the workshop, is financial support. The sums are not very large relative to other expenditures, for example, on science education, and certainly not relative to the expenditures that a few nations such as the United States are making in biodefense. But over the next several years they are likely to make the difference in whether the promising initiatives, described in Chapter 3 and expanded by the workshop participants, can be increased and, just as important, sustained.

Governments can play other roles in encouraging education about dual use issues. The United States offers a number of examples. As cited in Chapter 1, the 2009 *National Strategy for Countering Biological Threats* gives a prominent role to scientists to foster and sustain a culture of responsibility (White House 2009). The NSABB has offered general guidance through its *Strategic Framework for Outreach and Education on Dual Use Issues* (NSABB 2008). Since the 1990s the NIH has made RCR education a requirement for all student traineeships and postdoctoral fellowships, although it does not prescribe how the training will be carried out nor collect data on the number of students actually trained. The requirement announced in 2009 by the National Science Foundation (NSF) that all undergraduate and graduate students and postdoctoral fellows who receive NSF support to do their research must receive RCR education is an even broader mandate. The Select Agent Program that regulates research with a list of biological agents and toxins has requirements for laboratory security training, and there are proposals to expand this to include broader concepts of responsible conduct and personnel management (NRC 2009e).

As already mentioned, the NSABB and the U.S. State Department (reflecting wider interagency agreement) have proposed that education about dual use issues be mandatory (NSABB 2007, Rocca 2008). Participants in the Warsaw workshop, as in other international discussions (Mancini and Revill 2008, 2009; NRC 2009f), disagreed about the advisability and feasibility of imposing an educational requirement. The major advantage cited was the pressure this would provide to overcome the many barriers and impediments to expanding education beyond the current limited base. Some of the resistance to the idea was philosophical, reflecting a general objection to such government requirements. Some of the resistance was practical—given the current lack of faculty and materials, there was concern that mandates could not be successfully implemented. A few participants also noted that education in some countries is so clearly the responsibility of local or state/regional governments that national mandates would be futile (see also Garraux [2010] for a discussion of the example of Switzerland). And as described above, for some the wide array of methods by which courses are developed and adopted nationally, from the local and informal to the highly centralized, underscored the need to be flexible and to produce materials that can be adapted to a range of circumstances, even within a particular country.

Some participants also suggested other ways in which governments could encourage broader adoption of education on dual use issues short of a general mandate, such as by linking such education to funding agency requirements in ways analogous to the NIH and NSF RCR requirements that would target key audiences, or by using the accreditation process or other legal structures that govern degree requirements in some countries. Some participants suggested that research funders consider incentives as well as requirements, such as funding innovative efforts to train faculty or develop resources.

The Role of International Agreements and Organizations

This report has already given substantial attention to the contributions that the work of international organizations, as well as the implementation of international agreements, is already making to support for biosecurity, and, in a number of cases, to education about dual use issues. Two organizations, the WHO and UNESCO, along with the processes related to the Biological and Toxin Weapons Convention, stand out. WHO, through its studies of dual use issues (WHO 2005, 2007), has provided an important international endorsement of their importance that takes them beyond the realm of "just" security. Its role in biosafety training is even more important for the future of education of a broad research community that includes laboratory technical personnel. So far the role of UNESCO has been relatively limited, though staff members from the organization have participated in a number of international meetings, including the Warsaw workshop. And the organization was a co-sponsor of a general workshop on dual use issues at the Polish Academy of Sciences in 2007 (Polish Academy 2007). Given its longstanding support for science in the developing world and its many activities in both bioethics and broader science ethics, this is an organization that many participants hoped would become more engaged in the future.

One theme that emerged clearly in the discussions was the convening capacity of such organizations and the contributions that they can make to encouraging coordinated and sustained support from national governments. In addition, the upcoming BWC review conference in late 2011 was cited frequently as an example of opportunity to build upon the success of the 2005 and 2008 intersessional meetings and encourage broad support by member states for the initiatives cited in the reports of those meetings and at the 2006 review conference (BWC 2005, 2006, 2008). The report of the 2008 BWC states parties meeting specifically offers an opening:

> States Parties are encouraged to inform the Seventh Review Conference of, *inter alia*, any actions, measures or other steps that they may have taken on the basis of the discussions at the 2008 Meeting of Experts and the outcome of the 2008 Meeting of States Parties, in order to facilitate the Seventh Review Conferences consideration of the work and outcome of these meetings and its decision on any further action, in accordance with the decision of the Sixth Review Conference (BWC/CONF.VI/6, Part III, paragraph 7 (e)). (BWC 2008)

Discussions are taking place among some of the organizations active in education about dual use issues about how best to take advantage of the review conference to garner further support and commitments from states parties (Sture and Minehata, in press).

Conclusions

Based on its understanding of the materials and teaching approaches currently available as described in Chapter 3, on additional material cited above and in other chapters, and on the discussions at the Warsaw meeting, the committee concluded that:

- **Scientific organizations as well as professional associations are playing leading roles in developing international support for education about dual use issues. There are significant opportunities to build on this work to carry out more systematic and coordinated efforts.**
- **To enable dual use issues to become a regular part of the curriculum across the life sciences, significant sustained funding will be required to fill the gaps, such as the need for new materials in multiple languages, identified in the workshop and other reports.**
- **Private sources such as foundations have played and can continue to play an important role in supporting the development and implementation of education about dual use issues. Beyond any private resources, the sustained support of governments will be necessary.**
- **Governments can also play a number of other roles besides providing funds to encourage the expansion of education about dual use issues.**
- **Two international organizations have particularly important roles in encouraging education about dual use issues. WHO has a particular role in biosafety, while UNESCO could make significant contributions through its work in bioethics. In addition, the upcoming Seventh Review Conference of the Biological Weapons Convention in 2011 will provide an opportunity for member states to build on prior work and take affirmative steps in support of education about dual use issues.**

SUMMING UP: THE COMMITTEE'S RECOMMENDATIONS

In Chapter 3 the committee presented a number of its *findings* about the extent of current education about dual use issues internationally and the availability of online materials to support it. This has chapter offered a variety of *conclusions* that the committee reached based on the discussions at the Warsaw work and other material about gaps in current capabilities and needs that need to be filled if dual use issues are to become more included in the education of life scientists around the world. It also offered *conclusions* about some of the ways the gaps could be filled and the needs met. This section presents the committee's *recommendations* for what it believes will be most important for implementing more and more effective education on dual use issues for the life sciences community. Although the findings led to conclusions, not all of the conclusions led to recommendations because the committee wanted to focus attention on those it found to be the most important to achieving the larger goal.

General Approach

An introduction to dual use issues should be part of the education of every life scientist.

- **Except in specialized cases (particular research or policy interests), this education should be incorporated within broader coursework and training rather than carried out via stand-alone courses. Appropriate channels include biosafety, bioethics and research ethics, and professional standards (i.e., RCR), as well as inclusion of examples of research with dual use potential in general life sciences courses.**
- **Insights from research on learning and effective teaching should inform development of materials, approaches to teaching students, and to preparing faculty.**

Specific Actions

Achieving the broad goal of making dual use issues part of broader education will require a number of specific actions. They may be undertaken separately by different organizations, but there will be substantial benefit if there is an effort to coordinate across the initiatives and share successful practices and lessons learned. Resources will be needed to ensure that the initiatives are carried out at an appropriate scale and scope.

The workshop participants and the committee did not explore the implementation of any specific recommendations in sufficient depth to prescribe a particular mechanism or path forward. Instead, reflecting the diversity and variety of situations in which education about dual use issues will be carried out, the previous sections of this chapter have laid out of a number of options that could be used to implement each of the recommendations below. Some of the options, such as the models for train-the-trainer programs, are sufficiently well developed—or already under way—that implementation could be relatively straightforward if sustained support is available to expand their scale and scope. In other cases, such as developing evaluation and assessment methods, substantial additional work will be required to plan and implement any systematic effort.

- **Develop an international open access repository of materials that can be tailored to and adapted for the local context, perhaps as a network of national or regional repositories.**
  - **—The repository should be under the auspices of the scientific community rather than governments, although support and resources from governments will be needed to implement the teaching locally.**

— Materials should be available in a range of languages.
— Materials should interface with existing databases and repositories of educational materials dedicated to science education.

- **Develop additional case studies to address broader segments of the life sciences community, with a focus on making the case studies relevant to the student/researcher.**
- **Design methods for commenting and vetting of materials by the community (such as an appropriately monitored Wikipedia model) so they can be improved by faculty, instructors and experts in science education.**
- **Build networks of faculty and instructors through train–the-trainer programs, undertaking this effort if possible in cooperation with scientific unions and professional societies and associations.**
- **Develop a range of methods to assess outcomes and, where possible, impact. These should include qualitative approaches as well as quantitative measures, for example, of learning outcomes.**

REFERENCES

AAAS (American Association for the Advancement of Science). 2008. *Professional and Graduate-Level Programs on Dual Use Research and Biosecurity for Scientists Working in the Biological Sciences: Workshop Report*. Washington, DC: American Association for the Advancement of Science. Available at http://cstsp.aaas.org/files/AAAS_workshop_report_education_of_dual_use_life_science_research.pdf.

Bradford Disarmament Research Centre Website. 2010. Applied Dual-Use Biosecurity Education: Online Distance Learning Module 20 Masters Level Credits. Available at http://www.dual-usebioethics.net/.

Bügl, H., J. P. Danner, R. J. Molinari, J. Mulligan, D. A. Roth, R. Wagner, B. Budowle, R. M. Scripp, J. A. L. Smith, S. J. Steele, G. Church, and D. Endy. 2006. *A Practical Perspective on DNA Synthesis and Biological Security*. Presentation at the International Consortium for Polynucleotide Synthesis. December 4, 2006. Available at http://pgen.us/PPDSS.htm.

BWC (Biological and Toxin Weapons Convention). 2005. Report of the Meeting of the States Parties. Geneva: United Nations.

BWC. 2006. Sixth Review Conference of the States Parties to the Biological Weapons Convention. Final Document. Geneva: Biological Weapons Convention.

BWC. 2008. Report of the Meeting of States Parties. Geneva: United Nations.

Garfinkel, M. S., D. Endy, G. L. Epstein, and R. M. Friedman. 2007. Synthetic genomics: Options for governance. *Industrial Biotechnology* 3(4):333–365.

Garraux, F. 2010. Linking life sciences with disarmament in Switzerland. Pp.57-74 in *Education and Ethics in the Life Sciences: Strengthening the Prohibition on Biological Weapons*. B. Rappert, ed. Canberra, Australia: Australian National University E Press.

IAP. 2005. Statement on Biosecurity. Available at http://www.interacademies.net/CMS/About/3143.aspx>.

Israel Academy of Sciences and Humanities. 2008. *Biotechnological Research in an Age of Terrorism*. Jerusalem: Israel Academy of Sciences and Humanities.

KNAW (Royal Netherlands Academy of Arts and Sciences). 2007. A Code of Conduct for Biosecurity. Report by the Biosecurity Working Group. Amsterdam: Royal Netherlands Academy of Arts and Sciences. Available at: *http://www.knaw.nl/cfdata/publicaties/detail.cfm?boeken__ordernr=20071092.*

Korn, H., P. Berche, and P. Binder. 2008. *Les Menaces Biologiques—Biosécurité et Responsabilité des Scientifiques*. Paris: French Academy of Sciences. Available at http://www.academiesciences.fr/publications/rapports/ rapports_html/ rapportPUF_Korn.htm.

Mancini, G., and J. Revill. 2008. *Fostering the Biosecurity Norm: Biosecurity Education for the Next Generation of Life Scientists*. Como, Italy: Landau Network Centro Volta and Bradford Disarmament Research Centre.

Mancini, G., and J. Revill. 2009. *Promoting Sustainable Education and Awareness Raising on Biosecurity and Dual Use.* Como, Italy: Landau Network Centro Volta and Bradford Disarmament Research Centre.

NAE (National Academy of Engineering). 2009*. Ethics Education and Scientific and Engineering Research: What's Been Learned? What Should Be Done? Summary of a Workshop*. Washington, DC: National Academies Press.

NRC (National Research Council). 2003b. *Evaluating and Improving Undergraduate Teaching in Science, Technology, Engineering, and Mathematics*. Washington, DC: National Academies Press.

NRC. 2004a. *Biotechnology Research in an Age of Terrorism*. Washington, DC: National Academies Press.

NRC. 2006. *Globalization, Biotechnology, and the Future of the Life Sciences*. Washington, DC: National Academies Press.

NRC. 2009a. *On Being a Scientist*, 3rd edition. Washington, DC: National Academies Press.

NRC. 2009e. *Responsible Research with Biological Select Agents and Toxins*. Washington, DC: National Academies Press.

NRC. 2009f. *2nd International Forum on Biosecurity: Report of an International Meeting, Budapest, Hungary, March 30-April 2, 2008*. Washington, DC: National Academies Press.

NSABB (National Science Advisory Board for Biosecurity). 2007. Proposed Framework for the Oversight of Dual Use Life Sciences Research: Strategies for Minimizing the Potential Misuse of Research Information. Available at <http://www.biosecurityboard.gov/news.asp>.

NSABB. 2008. Strategic Plan for Outreach and Education on Dual Use Issues. Available at <http://oba.od.nih.gov/biosecurity/biosecurity_documents.html>.

Polish Academy of Sciences. 2007. The Advancement of Science and the Dilemma of Dual Use: Why We Can't Afford to Fail. Available at http://www.english.pan.pl/index.php?option=com_content&view=article&id=236:international-conference-on-dual-use&catid=57:archive&Itemid=88.

Pfund, C., S. Miller, K. Brenner, P. Bruns, A. Chang, D. Ebert-May, A. P. Fagen, J. Gentile, S. Gossens, I. M. Khan, J. B. Labov, C. M. Pribbenow, M. Susman, L. Tong, R. Wright, R. T. Yuan, W. B. Wood, and J. Handelsman. 2009. Summer institute to improve university science teaching. *Science* 342:470-471.

Rocca, C. 2008. Statement by H.E. Ambassador Christina Rocca, U.S. Representative to the Biological Weapons Convention, to the Annual Meeting of the Biological Weapons Convention States Parties, Geneva, Switzerland, December 1, 2008.

Royal Society. 2006. *Report of the international workshop on science and technology developments relevant to the BTWC*. London: Royal Society.

Smallwood, K. 2009. *Biosecurity, Biosafety and Dual Use Risks: Trends, Challenges, and Innovative Solutions*. Report. Como, Italy: Landau Network Centro Volta and Bradford Disarmament Research Centre.

Sture, J., and M. Minehata. In press. Dual-use education for life scientists: Mapping the current global landscape and developments. Report of the Bradford meeting, July 2010. Bradford, UK: Bradford Disarmament Research Centre.

UNAS (Uganda National Academy of Science). 2008. *Promoting Biosafety and Biosecurity Within the Life Sciences: An International Workshop in East Africa*. Kampala: Uganda National Academy of Sciences.

UNAS. 2009. *Establishing and Promoting Standards and Good Laboratory Practice (GLP) for Running Safe, Secure, and Sustainable Laboratories in Africa*. Kampala: Uganda National Academy of Sciences.

White House. 2009. *National Strategy for Countering Biological Threats*. Available at http://www.whitehouse.gov/sites/default/files/National_Strategy_for_Countering_BioThreats.pdf.

WHO (World Health Organization). 2005. *Life Science Research: Opportunities and Risks for Public Health*. Geneva: World Health Organization. Available at http://www.who.int/csr/resources/ publications/deliberate/WHO_CDS_CSR_LYO_2005_20.pdf.

WHO. 2006. *Biorisk Management: Laboratory Biosecurity Guidance.* Geneva: WHO.

WHO. 2007. Scientific Working Group on Life Science Research and Global Health Security: Report of the First Meeting. Geneva: WHO. Available at http:// www.who.int/csr/resources/publications/deliberate/WHO_CDS_EPR_2007_4.

WHO. 2010. WHO Biorisk Management Advanced Trainer Programme: Concept Sheet. Photocopy.

Wholey, J. S., H. P. Hatry, and K. E. Newcomer. 2004. *Handbook of Practical Program Evaluation*. San Francisco, CA: Jossey-Bass.

Appendix A

Committee Member Biographies

Vicki Chandler (NAS), *Chair*, is on leave from the University of Arizona where she holds the Carl E. and Patricia Weiler Endowed Chair for Excellence in Agriculture and Life Sciences and is a Regents' Professor in the Department of Plant Sciences and Molecular & Cellular Biology. She received her B.S. from the University of California, Berkeley and her Ph.D. from the University of California, San Francisco. Her research program investigates the regulation of gene expression with an emphasis on gene silencing in plants. Dr. Chandler received the College of Agriculture and Life Sciences Faculty Researchers of the Year Award in 2001 and was elected to the National Academy of Sciences in 2002. Currently Dr. Chandler is the Chief Program Officer for Science at the Gordon and Betty Moore Foundation in Palo Alto, California.

Jennifer Gaudioso is a Principal Member of the Technical Staff in the International Biological Threat Reduction Program at Sandia National Laboratories (SNL). Her work focuses on the responsible use of biological agents, equipment, and expertise at bioscience facilities, with an emphasis on risk assessment. Dr. Gaudioso has worked extensively on laboratory biorisk management issues internationally. She has consulted on these topics for basic and high containment bioscience laboratories in over thirty countries. In recent years, she has organized many international conferences, trainings, and workshops. Dr. Gaudioso led the design of SNL's training laboratory and associated course, Controlling Laboratory Biorisks. She has also participated in assessments at US government bioscience facilities, and contributed to the development of international biosecurity guidelines. She is author of numerous journal articles and has presented her research at national and international meetings. She also co-authored the Laboratory Biosecurity Handbook, published by CRC Press. Dr. Gaudioso serves on SNL's Institutional Biosafety Committee, and is an active member of the American Biological Safety Association. She earned her Ph.D. at Cornell University.

Andrzej Górski is Professor of Medicine and Immunology at The Medical University of Warsaw and Vice President of the Polish Academy of Sciences. He is Board certified in Internal Medicine with a subspecialty certification in clinical immunology. Dr. Górski received his M.D. (1970) and Ph.D. (1973) degrees from The Medical University of Warsaw and was a Fulbright Scholar at the Sloan-Kettering Institute for Cancer Research, USA. He has been a visiting professor at Adelaide Children's Hospital, Australia, the Weizmann Institute of Science, Israel, the University of London United Medical and Dental Schools of Guy's and St. Thomas's Hospitals, England, and the Universidad Autonoma, Madrid, Spain. Dr. Górski served as Prorector for Scientific Affairs & International Cooperation (1993-1996) and as Rector (1996-1999) of The Medical University of Warsaw. From 1999-2007 he was also Director of the L. Hirszfeld Institute of Immunology and Experimental Therapy at the Polish Academy of Sciences. Dr. Górski has authored over one hundred scientific publications, serves as the editor in chief of *Archivum Immunologiae et Therapiae Experimentalis*, and has served as a member of the Editorial Board of Science & Engineering Ethics. His awards include the Meller Award for excellence in cancer research from Sloan-Kettering Institute, the ICRETT Award and the Yamagiwa-Yoshida Award from the International Union Against Cancer, the J. Sniadecki Memorial Award from the Polish Academy of Sciences (the highest award in medical sciences in Poland), and the Gloria Medicinae, awarded by The Polish Medical Association. In addition, Dr. Górski is a member of the Committee for Ethics in Science at the Polish Academy of Sciences, a member of the Committee for Ethics in Science at the Ministry of Science, Head of the Bioethics Committee, Ministry of Health, and represents Poland in the Forum of National Ethics Committees to the European Commission.

Alastair Hay is Professor of Environmental Toxicology at the University of Leeds. He has worked on issues relating to chemical and biological warfare (CBW) for some 30 years. Much of his work has dealt with the need for workable international treaties which outlaw the use of CBW. Professor Hay has been involved in field expeditions in Iraq and Bosnia to investigate the use of chemical warfare agents. He has written extensively on the subject and helped prepare the World Health Organization's 2004 manual "Public health response to biological and chemical agents." Professor Hay chaired a small international working group on behalf of the International Union of Pure and Applied Chemistry and the Organization for the Prohibition of Chemical weapons which prepared educational material for chemists on multiple uses of chemicals, chemical warfare agents and codes of conduct.

Michael Imperiale is a Professor in the Department of Microbiology and Immunology at the University of Michigan Medical School. He joined the department in 1984 as the Arthur F. Thurnau Assistant Professor of Microbiology and Immunology and was subsequently promoted to Associate Professor in 1990 and Professor in 1996. Before joining the University of Michigan, Dr. Imperiale carried out research training as a postdoctoral fellow at The Rockefeller University, where he first became interested in DNA tumor viruses, studying gene regulation in the human pathogen, adenovirus. He received his undergraduate and graduate training at Columbia University, receiving a B.A. in 1976, M.A. in 1978, and Ph.D. in 1981, all in biological sciences. Currently, Dr. Imperiale's research interests focus on the study of how DNA tumor viruses interact with the host immune system, how they contribute to oncogenesis, how they traffic within the cell, and how they assemble. Dr. Imperiale is a member of the National Science Advisory Board for Biosecurity, a position he has held since 2005. He also serves as an editor of the *Journal of Virology*.

Gabriel Ogunmola is Chairman of the International Council for Science Regional Committee for Africa and the executive director of the Science and Technology Development Foundation in Ibadan, Nigeria. His research interests include biophysical chemistry; structure function relationships in macromolecules, protein and DNA, chemistry, molecular pathology of hemoglobins and enzymenopathies. He is also a member of the Network of African Science Academies and president of the Nigerian Academy of Sciences. Dr. Ogunmola attended Princeton University as a Fulbright Scholar and holds a Ph.D.

Sergio Jorge Pastrana is Foreign Secretary of the Cuban Academy of Sciences. Sergio Jorge Pastrana was born in Havana, Cuba, in 1950. He graduated from the School of Letters and Arts of the University of Havana in History of English Literature and Culture in 1975, and he has done postgraduate studies at the Institute of International Relations of the Ministry of Foreign Relations of Cuba. His interests on international cooperation relate to the history of early international contacts of the Cuban scientific community, and its influence on the building of a national scientific capacity in Cuba, a subject on which he has published and lectured both in Cuba and abroad. Pastrana has been a member of the Caribbean Academy of Sciences since 2000, and he is also a member of the Board of the Caribbean Scientific Union, an organization of all academies of sciences of the Wider Caribbean Basin. He is a representative of the Cuban Academy to the Executive Council of the Inter Academy Panel on International Issues since 2003, where he has been directly involved in the groups coordinating initiatives on Biosecurity and Genetically Modified Organisms, and presently chairs the Membership Committee.

Susan Singer is Laurence McKinley Gould Professor of the Natural Sciences in the Department of Biology at Carleton College, where she has been since 1986. From 2000 to 2003 she directed the Perlman Center for Learning and Teaching, then took a research leave supported by a Mellon new directions fellowship. She chaired the Biology Department from 1995 to 1998 and was a National Science Foundation program officer for developmental mechanisms from 1999 to 2001. In her research, she investigates the evolution, genetics, and development of flowering in legumes; many of her undergraduate students participate in this research. She is actively engaged in efforts to improve undergraduate science education and received the Excellence in Teaching award from the American Society of Plant Biology in 2004. She helped to develop and teaches in Carleton's Triad Program, a first-term experience that brings students together to explore a thematic question across disciplinary boundaries. She is a member of the Project Kaleidoscope Leadership Initiative national steering committee and has organized PKAL summer institutes and workshops. At the National Research Council, she was a member of the Committee on Undergraduate Science Education and the Steering Committee on Criteria and Benchmarks for Increased Learning from Undergraduate STEM Instruction and chaired the Committee on High School Science Laboratories: Role and Vision; currently she serves on the Board on Science Education and is a science consultant to the NRC Science Learning Kindergarten to Eighth Grade study. She has B.S., M.S., and Ph.D. degrees, all from Rensselaer Polytechnic Institute.

Geoffrey Smith is a British virologist and medical research authority in the area of vaccinia virus and the family of poxviruses. He is Head of the Department of Virology at Imperial College London. Smith completed his bachelor's degree at the University of Leeds in 1977 and in 1981 gained a Ph.D. in Virology while in London. Between 1981 and 1984, while he was working in the United States under the National Institutes of Health, Smith developed and pioneered the use of genetically engineered live vaccines. Between 1985 and 1989 he lectured at the University of Cambridge.

Prior to 2002, he was based at the Sir William Dunn School of Pathology at the University of Oxford. Between 1988 and 1992 his work was funded by the Jenner Fellowship from The Lister Institute; he became a governor of the Institute in 2003. In 1992 the Society for General Microbiology awarded Smith their Fleming Award for outstanding work by a young microbiologist. In 2002, Smith was elected as a fellow of the Academy of Medical Sciences. In 2003, he was invited to become a fellow of the Royal Society and in 2005 was awarded the Feldburg Foundation Prize for his work on poxviruses. Smith was editor in chief of the *Journal of General Virology* up until 2008 and chairs the WHO's Advisory Committee on Variola Virus Research. As of 2009 he remains the Head of the Department of Virology at Imperial College London and is president-elect of the International Union of Microbiological Societies.

Lei Zhang is a professor and director of international affairs at the Institute of Biophysics of the Chinese Academy of Sciences. Her research area is soil microbiology. She received her Ph.D. in 2003 at Auburn University. She had been working in Eastern Michigan University before joining the Institute of Microbiology of the Chinese Academy of Sciences at the end of 2004, where she served as a professor and the director of the office of International Affairs at the Institute.

Appendix B

List of Workshop Participants and Agenda

Workshop on Dual Use Education in the Life Sciences
Polish Academy of Sciences
Staszic Palace
Nowy Świat 72
Warsaw

15–18 November 2009

WORKSHOP PARTICIPANTS

Name, Organization

Nisreen Al-Hmoud, *Royal Scientific Society*, Jordan
Sabah Al-Momin, *Kuwait Institute of Scientific Research*, Kuwait
Carl-Gustav Anderson, *The National Academies*, USA
Mamedyar Azaev, *Vector State Research Center of Virology and Biotechnology,* Russia
Spencer Benson, *University of Maryland*, USA
Louise Bezuidenhout, *University of Exeter*, United Kingdom
Katherine Bowman, *The National Academies*, USA
Robert Butera, *Georgia Institute of Technology*, USA
Brian Carter, *Department of State*, USA
Vicki Chandler, *Gordon and Betty Moore Foundation*, USA
Marie Chevrier, *University of Texas at Dallas*, USA

Tech Mean Chua, *Asia Pacific Biosafety Association*, Singapore
John Crowley, *United Nations Educational, Cultural and Scientific Organization*, France
B. C. Das, *University of Delhi*, India
Neil Davison, *The Royal Society*, United Kingdom
Clarissa Dirks, *The Evergreen State College*, USA
Adam Fagen, *The National Academies*, USA
Khalid Fares, *Moroccan Society of Biochemistry and Molecular Biology*, Morocco
Åke Forsberg, *Swedish Defense Research Establishment*, Sweden
David Franz, *Midwest Research Institute*, USA
Katsu Furukawa, *Japan Science and Technology Agency*, Japan
Jennifer Gaudioso, *Sandia National Laboratories*, USA
Grzegorz Gawlik, *Export Management, Inc.*, Poland
Andrzej Górski, *Polish Academy of Sciences*, Poland
Anfeng Guo, *Beijing Science Technology and Security Center*, China
Krzysztof Guzik, *Jagiellonian University*, Poland
Alastair Hay, *University of Leeds*, United Kingdom
Linda Hecker, *Landmark College*, USA
Sara Heesterbeek, *Royal Netherlands Academy of Arts and Sciences*, Netherlands
Jo L. Husbands, *The National Academies*, USA
Michael Imperiale, *University of Michigan Medical School*, USA
Michael Kleiber, *Polish Academy of Sciences,* Poland
Pioter Laidler, *Jagiellonian University*, Poland
Andrzej Legocki, *Polish Academy of Sciences*, Poland
Pamela Lupton-Bowers, *PLB Consulting*, United Kingdom
Irma Makalinao, *University of the Philippines*, Philippines
Giulio Mancini, *Landau Network*, Italy
Seumas Miller, *Charles Sturt University* and Australian National University, Australia
Piers Millett, *BWC Implementation Support Unit*, Switzerland
Masamichi Minehata, *University of Bradford*, United Kingdom
Nishal Mohan, *Federation of American Scientists*, USA
Bryan Muñoz Castillo, *Inter-American Institute for Cooperation on Agriculture*, Costa Rica
Anwar Nasim, *OIC Standing Committee on Scientific and Technological Cooperation (COMSTECH)*, Pakistan
Karen Oates, *National Science Foundation*, USA
Gabriel Ogunmola, *Regional Committee for Africa, International Council for Science;* and *Science and Technology Development Foundation*, Nigeria
Sergio Jorge Pastrana, *Cuban Academy of Sciences*, Cuba
William Pinard, *American Association for the Advancement of Science*, USA

Brian Rappert , *Exeter University*, United Kingdom
James Revill, *University of Bradford*, United Kingdom
Benjamin Rusek, *The National Academies*, USA
Barbara Schaal, *Washington University;* and *The National Academies,* USA
Susan Singer, *Carleton College*, USA
Geoffrey Smith, *Imperial College London*, United Kingdom
Daniel Sordelli, *University of Buenos Aires*, Argentina
Marek Szczygieł, *Ministry of Foreign Affairs*, Poland
Terence Taylor, *International Council for the Life Sciences;* and *Global Health and Security Initiative, Nuclear Threat Initiative,* USA
Khalid Temsamani, *Moroccan Biosafety Association*, Morocco
Willy Tonui, *African Biosafety Association*, Kenya
Klintsy Torres-Hernández, *Mexican Biosafety Association*, Mexico
Cristina Vargas, *Centers for Disease Control and Prevention*, USA
Cindy Vestergaard, *Danish Institute of International Studies*, Denmark
Simon Whitby, *University of Bradford*, United Kingdom
Henk Zandvoort, *Delft University of Technology*, Netherlands
Lei Zhang, *Chinese Academy of Sciences*, China

WORKSHOP AGENDA

Sunday, 15 November
Staszic Palace

19:00 **Welcome Reception and Dinner**

Opening remarks from sponsoring organizations

- Polish Academy of Sciences—Michal Kleiber, President
- U.S. National Academy of Sciences—Barbara Schaal, Vice-President
- InterAcademy Panel on International Issues—Sergio Pastrana, Foreign Secretary, Cuban Academy of Sciences
- International Union of Biochemistry and Molecular Biology—Andrzej Legocki, Polish Academy of Sciences
- International Union of Microbiological Societies—Daniel Sordelli, President
- U.S. Department of State—Brian Carter, Biosecurity Engagement Program

Monday, 16 November
Staszic Palace

8:00 Registration

9:00–10:45 **Plenary**

Chair: Andrzej Górski, Polish Academy of Sciences

- Introduction to the Forum
  - — Goals of the Forum—Vicki Chandler, Betty and Gordon Moore Foundation
  - — Concepts and Definitions—Michael Imperiale, University of Michigan
- Keynote Address: "Insights from the Science of Learning"—Susan Singer, Carleton College
  This plenary session will introduce concepts from the science of teaching and learning that can provide the context for developing effective methods of teaching about dual use research issues. Professor Singer's presentation will draw from the literature on how people learn and on developments in science education research over the last several decades.
  - — Discussion (~30 minutes)

10:45–11:15 Break

11:15–12:15 **Plenary**

Chair: Andrzej Górski, Polish Academy of Sciences

- Keynote Address: "Talking to Scientists About Social Responsibility"— Henk Zandvoort, Delft University of Technology
  This plenary session will focus on experiences preparing scientists and engineers for social responsibility. Professor Zandvoort's presentation will incorporate discussion of both the policies and practices of teaching about the ethical aspects of sciences, including examples from the field of synthetic biology.
  — Discussion (~30 minutes)

12:15–13:15 Lunch

13:15–14:30 **Plenary**

Chair: Sergio Pastrana, Cuban Academy of Sciences

- Introduction of Breakout Session Topics and Tasks for the Afternoon— Alastair Hay, Leeds University
  The afternoon's sessions are intended to provide a baseline summary of activities. This will enable participants to identify gaps and needs in anticipation of the discussions on the next day about how the gaps can be filled and needs met.
- To provide a basis for discussion, speakers will present their research on the current status of dual use education in Europe, Japan, and the United States. Workshop participants may also draw on another background paper by Cheryl Vos on "Available Online Resources."
  — "Current Status of Dual Use Education in Europe and Japan" (paper by Giulio Mancini, Masamichi Minehata, James Revill, and Nariyoshi Shinomiya)— Presentation by James Revill, University of Bradford
  — "Current Status of Dual Use Education in the United States"— Presentation by William Pinard, American Association for the Advancement of Science
- Initial discussion, Q&A

14:45–17:15 **Breakout Session #1**
These sessions will expand on the information provided in the plenary and the background papers to provide a more complete picture of what is happening globally.

Group A: Chair: David Franz. Rapporteur: Jo Husbands
Group B: Chair: Jennifer Gaudioso. Rapporteur: Ben Rusek
Group C: Chair: Daniel Sordelli. Rapporteur: Adam Fagen
Group D: Chair: Lei Zhang. Rapporteur: Katie Bowman

16:00–16:30 Break (taken during the session)

17:30 **Reception and Networking Session** (Staszic Palace)
The reception will recognize and honor the special contributions by the late Sir Joseph Rotblat and Professor Maciej Nalecz to the Pugwash Conferences on Science and World Affairs. Professors Andrzej Górski and Janusz Komender will briefly discuss the contributions to raising awareness among scientists about issues of social responsibility made by these two outstanding members of Polish Pugwash.

The networking session is intended to enable participants to share information in an informal environment about their activities and experiences. Participants will have the opportunity to discuss their ongoing work related to biosecurity, dual use, and/or education to continue the discussions from the first afternoon and help prepare for the discussions the following day.

Tuesday, 17 November
Staszic Palace

9:00–10:30 **Plenary**
Chair: Gabriel Ogunmola, Nigerian Academy of Sciences
- Reports from the Four Working Groups—The rapporteurs will synthesize the responses and present the consolidated results.
- Introduction of Next Breakout Sessions—Jennifer Gaudioso, Sandia National Laboratories
  The breakout sessions will address a series of topics that, taken together, will provide a programme of

action to support widespread implementation of dual use education as part of the training of life scientists. Participants will be divided into 4 groups, with the opportunity to change groups after lunch.
- Discussion, Q&A (~30 minutes)

10:30–11:00 Coffee break

11:00–13:00 **Breakout Session #2**
These breakout sessions will focus on specific topics related to resources and methods for dual use education.

Group A: *Approaches to engaged teaching and learning* (seminars, simulations and role-playing, interactive online approaches, etc.)
Chair: Clarissa Dirks. Rapporteur: Louise Bezuidenhout

Group B: *Teaching materials and curriculum content* (topics, types of materials, resources for faculty, etc.)
Chair: Alastair Hay. Rapporteur: Sara Heesterbeek

Group C: *Motivating "students"* (policy and ethical issues useful for raising awareness and engaging scientists in dual use problems)
Chair: Karen Oates. Rapporteur: Carl Anderson

Group D: *Preparing faculty* (train-the-trainer, summer institutes, networks, etc.)
Chair: Spencer Benson. Rapporteur: Cristina Vargas

13:00–14:00 Lunch

14:00–15:15 **Plenary**
Chair: Lei Zhang, Chinese Academy of Sciences
This session will offer a demonstration of two new projects that offer examples of Internet resources that could be of interest to many participants.
- "Virtual Biosecurity Center"—Nishal Mohan, Federation of American Scientists
- "Bradford University Train-the-Trainer Project"—Simon Whitby, University of Bradford
- Discussion and Q&A (~30 minutes)

15:15–17:15 **Breakout Session #3**
These breakout sessions will focus on issues that must be addressed to enable dual use education to be implemented widely as part of the education of life scientists.

Group A: *Including dual use issues in existing education/training programs* (bioethics, biosafety, responsible conduct of research)
Chair: Marie Chevrier. Rapporteur: Giulio Mancini

Group B: *Developing models to foster and support education/training* (centers of excellence, regional networks, virtual networks, clearinghouses)
Chair: Seumas Miller. Rapporteur: Nishal Mohan

Group C: *Promoting and sustaining dual use issues by scientific organizations* (scientific societies, scientific unions, academies of sciences)
Chair: Sergio Pastrana. Rapporteur: Neil Davison

Group D: *Engaging the scientific community in dual use education* (engaging faculty and institutional leadership)
Chair: Khalid Temsamani. Rapporteur: Robert Butera

16:00–16:30 Break (taken during breakout session)

19:00 Conference dinner (Café Zamek, Pl. Zamkowy 4)

Wednesday, 18 November
Staszic Palace

9:00–10:45 **Plenary**
Chair: Geoffrey Smith, Imperial College London
- Summary of Breakout Sessions from Tuesday
- Reports from the Rapporteurs of the Eight Breakout Sessions
- Discussion (~30 minutes)

10:45–11:15 Coffee break

11:15–12:30	**Plenary: Summary of the Meeting** *Chair:* Vicki Chandler, Gordon and Betty Moore Foundation • Discussion of Lessons/Next Steps • Suggestions for the Workshop Report
12:30	Meeting Adjourns/Informal Lunch

Appendix C

Recognizing the Importance of Education

This appendix contains additional information to supplement Chapter 1's account of the growing interest in education as part of international strategies to create the "web of prevention" needed to address the potential security risks posed by rapid advances in the life sciences. It was prepared by project staff and draws heavily on the background chapters from two earlier NRC reports on biosecurity and dual use issues (2009d,f).

The Biological and Toxin Weapons Convention (BWC) includes a provision for a review conference every five years to assess the operation of the Convention. The final declaration of the second review conference in 1986 noted the importance of education about the obligations of the BWC and the Geneva Protocol as part of the "necessary measures [by States Parties] to prohibit or prevent any acts or actions which would contravene the Convention" (BWC 1986:4).[1] Similar acknowledgment of the role of education appears in subsequent review conference declarations.

National and international scientific organizations with policy interests related to biological weapons have been active on issues of disarmament and nonproliferation for many years. The emphasis on education and the engagement of the broader international scientific community has been more recent, however. In 1999, for example, the British Medical Association published *Biotechnology, Weapons, and Humanity*, which called

[1] The precise language is: "inclusion in textbooks and in medical, scientific and military educational programmes of information dealing with the prohibition of bacteriological (biological) and toxin weapons and the provisions of the Geneva Protocol" (BWC 1986:4).

for increased awareness of the dangers posed by biological weapons and the need to support the norms against them. The report called for fostering public debate about the "ethical and scientific issues surrounding biotechnology and its possible uses in warfare" (BMA 1999:102). In a 2002 submission to the UK Foreign and Commonwealth for a paper on ways to strengthen the BWC, the Royal Society included the recommendation that: "Consideration should be given to some formal introduction of ethical issues into academic courses, perhaps at undergraduate and certainly at postgraduate level" (Royal Society 2002:4). Also in 2002, the International Committee of the Red Cross launched its own *Biotechnology, Weapons, and Humanity* initiative, calling for a "web of prevention" to address the risks that technologies from the life sciences could be used for hostile purposes. In addition to a number of proposals for national and international legal measures to support implementation of the BWC, the initiative recommended including education about the risks of misuse as part of overall ethical training for life scientists.[2]

The anthrax mailings in October 2001 in the United States dramatically increased attention to the potential risks of bioterrorism, especially in that country. In October 2003, the U.S. National Research Council released the prepublication version of a report that focused specifically on the potential risks of research with dual use potential, *Biotechnology Research in an Age of Terrorism*, often called the "Fink report" after the study's chair, Gerald Fink of MIT (NRC 2004a). Planning for the project had begun prior to the September 11 attacks and the anthrax mailings, but those events gave the report much greater visibility. The report contained a strong statement about the responsibilities of life scientists.

> The Committee believes that biological scientists have an affirmative moral duty to avoid contributing to the advancement of biowarfare or bioterrorism. Individuals are never morally obligated to do the impossible, and so scientists cannot be expected to *ensure* that knowledge they generate will never assist in advancing biowarfare or bioterrorism. However, scientists can and should take reasonable steps to minimize this possibility. The Committee believes that it is the responsibility of the research community, including scientific societies and organizations, to define what these reasonable steps entail and to provide scientists with the education, skills, and support they need to honor these steps (NRC 2004a:112).

The report made a series of recommendations about how to meet these responsibilities, largely focused on enhancing self-governance by the sci-

[2] More information may be found at http://www.icrc.ch/Web/eng/siteeng0.nsf/html/bwh!Open.

entific community. With regard to education, the report recommended that "national and international professional societies and related organizations and institutions create programs to educate scientists about the nature of the dual use dilemma in biotechnology and their responsibilities to mitigate its risks" (NRC 2004a:111). Several subsequent NRC reports echoed the basic education recommendation (NRC 2004b; 2006; 2009d,f).

A number of national and international developments strengthened support for education as part of addressing potential dual use risks. The charter of the U.S. National Science Advisory Board for Biosecurity (NSABB), created in March 2004 to advise the U.S. government on a range of biosecurity issues, includes a mandate to "provide recommendations on the development of programs for outreach education and training in dual use research issues for all scientists and laboratory workers at federally-funded institutions" (NSABB 2008b:2). In the fall of 2004 a workshop convened by the Royal Society and the Wellcome Trust led to the recommendation that "education and awareness-raising training are needed to ensure that scientists at all levels are aware of their legal and ethical responsibilities and consider the possible consequences of their research" (Royal Society 2004:1).[3]

As discussed in Chapter 1, in March 2005 three major international scientific organizations—the IAP,[4] the International Council for Science (ICSU),[5]

[3] "University department heads, research institute directors, vice chancellors and Universities UK would be ideally placed to take this forward for the academic community. However, these bodies would need to be co-ordinated. The Association of British Pharmaceutical Industries and the BioIndustry Association could take the lead for industrial training" (Royal Society 2004:1).

[4] The IAP, the Global Network of Academies of Science, founded in 1993, is a global network of over 100 science academies. It is designed "to help its members develop the tools they need to participate effectively in science policy discussions and decision-making." As one of its major activities, the IAP issues statements that are endorsed by its member academies; the first two statements, on population (1994) and urban development (1996) were timed to coincide with special sessions of the United Nations on those topics. The IAP created a Working Group on Biosecurity in 2004; its members were the academies of China, Cuba, the Netherlands (chair until 2009), Nigeria, the United Kingdom and the United States. The Polish Academy of Sciences became a member and chair in early 2010. The IAP website is http://www.interacademies.net/.

[5] The International Council for Science (ICSU), founded in 1931, is a non-governmental organization representing a global membership that includes both national scientific bodies (111 members) and international scientific unions (29 members). As its website notes: "Because of its broad and diverse membership, the Council is increasingly called upon to speak on behalf of the global scientific community and to act as an advisor in matters ranging from ethics to the environment." Approximately a dozen of ICSU's unions can be considered part of the "life sciences"— reflecting the breadth and fragmentation of the field, unlike the single unions for physics and chemistry. ICSU also has a standing Committee on Freedom and Responsibility in the Conduct of Science. The ICSU website is http://www.icsu.org/index.php.

and the InterAcademy Medical Panel[6]—held the First International Forum on Biosecurity at a conference center in Como, Italy. Just over fifty participants from 20 developed and developing countries and several international organizations took part in the Forum.[7] The forum focused on three topics—codes of conduct, "sensitive" information and publication policy, and research oversight—that reflected key issues for the scientific community at the time. The rules of the forum precluded reaching formal conclusions or making recommendations, but the ideas generated in the working sessions were summarized and circulated informally among the convening organizations as a basis for their future activities. At its meeting in April 2005, for example, the ICSU Executive Board endorsed further work on biosecurity by the organization and its member unions, setting the stage for further engagement and collaboration.

Later in 2005 the BWC offered an important opportunity to promote one vehicle for education on dual use issues. Three years earlier, following the collapse of efforts to negotiate a protocol to the Biological Weapons Convention to provide for verification of treaty compliance, the states parties agreed to a series of intersessional meetings before the next full treaty review conference in 2006. Each year focused on a different topic and included both a meeting of experts and a subsequent meeting of the states parties. The topic chosen for 2005 was "content, promulgation, and adoption of codes of conduct for scientists."[8] Although the session was not focused directly on education, codes offer a tool for educating about scientific responsibility and some codes include specific calls for education (Rappert 2004). A number of international scientific organizations were invited to make presentations to the experts meeting. A number of countries also made relevant statements about the importance of education during the experts and states parties meetings and the final report of the states parties meeting included a number of relevant recommendations (BWC 2005; Rappert, Chevrier, and Dando 2006).

In addition to the activities and outcomes of the 2005 BWC intersessional meetings themselves, a number of scientific organizations under-

[6] The InterAcademy Medical Panel (IAMP), launched in 2000, is a global network of 64 academies of science and medicine, committed to improving health world-wide. IAMP activities focus on "institutional collaboration to strengthen the role of all academies to alleviate the health burdens of the world's poorest people; build scientific capacity for health; and provide independent scientific advice on promoting health science and health care policy to national governments and global organizations." The IAMP website is http://www.iamp-online.org/.

[7] The agenda and participants list, as well as other information and copies of the presentations may be found at http://www.nationalacademies.org/biosecurity.

[8] Additional information about the topics and contents of other intersessional meetings may be found at http://www.opbw.org/ under "Strengthening the Convention."

took special efforts inspired by the opportunity the forum presented. For example, the IAP prepared a Statement on Biosecurity intended as a guide for academies and other scientific bodies preparing codes of conduct, which includes "education and information" as one of the core elements that should be addressed: "Scientists should be aware of, disseminate information about and teach national and international laws and regulations, as well as policies and principles aimed at preventing the misuse of biological research" (IAP 2005).[9] The Statement was introduced in Geneva in draft form during the experts meeting and the final version, endorsed by 69 IAP member academies, was released in time for the states parties meeting at the end of the year.

Over the next several years, a number of universities and organizations, especially in the United States and the United Kingdom, began to produce materials and develop courses related to biosecurity and dual use issues. These activities and resources are discussed in Chapter 3.

The sixth BWC review conference in 2006 included the standard endorsement of education in its final document, but in greater detail than earlier statements and with a special acknowledgement of the need to raise awareness of those doing research with dual use potential.

> The Conference urges the inclusion in medical, scientific and military educational materials and programmes of information on the Convention and the 1925 Geneva Protocol. The Conference urges States Parties to promote the development of training and education programmes for those granted access to biological agents and toxins relevant to the Convention and for those with the knowledge or capacity to modify such agents and toxins, in order to raise awareness of the risks, as well as of the obligations of States Parties under the Convention. (BWC 2006:11)

In addition, the new series of intersessional meetings agreed upon at the review conference included as one of the two topics to be addressed in 2008 "Oversight, education, awareness raising, and adoption and/or development of codes of conduct with the aim of preventing misuse in the context of advances in bio-science and bio-technology research with the potential of use for purposes prohibited by the Convention." This provided another focal point for encouraging efforts by scientific organizations to promote education on dual use issues.

Development also continued at the national level. For example, in June 2007 the NSABB issued its *Proposed Framework for the Oversight of Dual Use Life Sciences Research: Strategies for Minimizing the Potential Misuse*

[9] The other elements are Awareness, Safety and Security, Accountability, and Oversight. The full statement may be found at http://www.interacademies.net/Object.File/Master/5/399/Biosecurity%20St..pdf.

of Research Information, which included two important recommendations dealing with awareness and education.

> *Awareness.* Researchers, research personnel, and research administrators should be fully aware of dual use research concerns, issues, and policies. An enhanced culture of awareness is essential to an effective system of oversight and is a critical step in scientists taking responsibility for the dual use potential of their work.
>
> *Education.* Awareness will be enhanced through ongoing, mandatory education about dual use research issues and policies. This will ensure that all individuals engaged in life sciences research are aware of the concerns and issues regarding dual use research and their roles and responsibilities in the oversight of such research.
>
> The federal government should develop training and guidance materials on federal requirements that can be used as educational resources at the local level. Furthermore, scientific societies, professional associations, and others in the private sector have an important contribution to make in promoting a culture of awareness and responsibility by educating broadly about dual use research, the associated tenets of responsible research, and the best practices in identifying and overseeing dual use research. The federal government can foster the development of such private sector training and education initiatives by providing appropriate resources for their development. Research institutions and associations should utilize these materials, tailoring them as needed to different audiences as part of promoting an awareness of dual use research issues among those involved in life sciences research. (NSABB 2007:9)

As of late 2010 the proposed framework was still undergoing review within the U.S. government, but if adopted the requirement for education across all the federal agencies, funding life sciences research would be significant. The potential impact on the United States is obvious, but it seems likely that the effects would spread through the extensive networks of international scientific collaboration supported by federal agencies.

In March 2008 a number of international scientific organizations—the IAP, the IAMP, the International Union of Biochemistry and Molecular Biology (IUBMB), the International Union of Biological Sciences (IUBS), and the International Union of Microbiological Societies (IUMS)—convened the Second International Forum on Biosecurity in Budapest, Hungary, with the Hungarian Academy of Sciences as the host. More than eighty people from 31 countries and six international organizations took part.[10] In part in anticipation of the BWC intersessional meetings later that year,

[10] The agenda and participants list may be found at http://www.nationalacademies.org/biosecurity; a summary report of the meeting (NRC 2009f) may be found at http://www.nap.edu/catalog.php?record_id=12525.

one of the topics of the meeting was building "a culture of responsibility within the science community regarding biosecurity through education and awareness raising, codes of conduct and other mechanisms." The other two topics were developing systems for research oversight, and enhancing the role of international scientific organizations as advisors on biosecurity issues. The Forum did not produce conclusions or recommendations, but the summary report of the meeting notes:

> Education was a common strategy emphasized by the three working groups to help move toward greater awareness of dual use issues, and ultimately toward greater consensus about risks and risk management strategies within the scientific community. The Forum discussions included suggestions to begin educational efforts by highlighting the many benefits arising from scientific developments, to incorporate specific historical examples of previous misuse of science, and also to promote active thinking and learning about biosecurity. A number of participants suggested that States Parties to the BWC should commit to taking steps to advance education and that national and international scientific organizations should promote the need for biosecurity education as well. The engagement of multiple stakeholders in the creation of codes of conduct was seen by many workshop participants as one opportunity to further such educational objectives. Beyond the creation of codes of conduct, participants suggested that discussions of the potential risks of misuse from life sciences advances, responsible conduct of science, and the existence of the BWC should be incorporated into academic training programs, although there was recognition that this would be a difficult task. (NRC 2009f:68)

As in 2005, the BWC intersessional meeting in 2008 included presentations by a wide array of governments, scientific and other organizations, and individual experts. Several academies of science and international unions took part by special invitation of the meeting chair or as part of national delegations.[11] The U.S. State Department also announced its support for the international workshop about education on dual use issues that is the centerpiece of this report.

During the States Parties meeting, the U.S. representative made an important additional statement of U.S. support for education: "The U.S. believes that such education should be a mandatory aspect of graduate education in the life sciences in the broader context of professional responsibility, and that this meeting should urge States Parties to explore and undertake such efforts" (Rocca 2008:3). The final report of the meeting

[11] An extensive collection of materials from the experts and states parties meetings videos, may be found on the UN Geneva Office on Disarmament website at http://www.unog.ch/80256EE600585943/(httpPages)/92CFF2CB73D4806DC12572BC00319612?OpenDocument.

included a number of specific suggestions for further action on education, although it only called for consideration of mandatory education:

> States Parties recognized the importance of ensuring that those working in the biological sciences are aware of their obligations under the Convention and relevant national legislation and guidelines, have a clear understanding of the content, purpose and foreseeable social, environmental, health and security consequences of their activities, and are encouraged to take an active role in addressing the threats posed by the potential misuse of biological agents and toxins as weapons, including for bioterrorism. States Parties noted that formal requirements for seminars, modules or courses, including possible mandatory components, in relevant scientific and engineering training programmes and continuing professional education could assist in raising awareness and in implementing the Convention. (BWC 2008:6-7)

States Parties agreed on the value of education and awareness programmes:

> (i) Explaining the risks associated with the potential misuse of the biological sciences and biotechnology;
> (ii) Covering the moral and ethical obligations incumbent on those using the biological sciences;
> (iii) Providing guidance on the types of activities which could be contrary to the aims of the Convention and relevant national laws and regulations and international law;
> (iv) Being supported by accessible teaching materials, train-the-trainer programmes, seminars, workshops, publications, and audio-visual materials;
> (v) Addressing leading scientists and those with responsibility for oversight of research or for evaluation of projects or publications at a senior level, as well as future generations of scientists, with the aim of building a culture of responsibility;
> (vi) Being integrated into existing efforts at the international, regional and national levels. (BWC 2008:7)

Expressions of support for education have continued to grow since 2008. A workshop organized by the American Association for the Advancement of Science (AAAS) produced the general recommendation that "the scientific, ethical, and legal issues related to identifying and addressing issues related to dual use life sciences research should be taught to American and foreign scientists working in the life sciences in the U.S., with due consideration to relevance and flexibility of educational curricula at the institution," and a long list of more specific proposals (AAAS 2008:5-6). The Federation of American Societies of Experimental Biology (FASEB) also issued a statement in March 2009 that it believed "scientists working in the life sciences have an obligation to be aware of the potential dual use nature of their research" and announcing its support for a number of principles related to education, including:

> Dual use research and biosecurity education must be an integral part of the training scientists receive in the responsible conduct of research. Scientists and laboratory personnel at any level of training or career development who are engaged in research at the laboratory bench or clinic should be aware of the risks associated with the potential misuse of life sciences research (FASEB 2009).

Taken together, the level of interest in and support for education about dual use issues has grown substantially and there appears to be an opportunity for a genuine expansion of activities in many parts of the world.

BIOSECURITY ACTIVITIES BY ACADEMIES AND SCIENTIFIC UNIONS

U.S. National Academy of Sciences: *Biotechnology Research in an Age of Terrorism* **(2004)** http://www.nap.edu/catalog.php?record_id=10827[12]

Royal Society—Wellcome Trust: *Do No Harm: Reducing the Potential for the Misuse of Life Science Research* **(2004)** http://www.wellcome.ac.uk/stellent/groups/corporatesite/@policy_communications/documents/web_document/wtx023408.pdf

IAP—International Council for Science (ICSU)—InterAcademy Medical Panel (IAMP): *1st International Forum on Biosecurity* **(2005)** http://www.icsu.org/5_abouticsu/INTRO_UnivSci_2.html

IAP: *Statement on Biosecurity* **(2005)** http://www.nationalacademies.org/biosecurity

International Union of Biochemistry and Molecular Biology (IUBMB): *Code of Ethics of the International Union of Biochemistry and Molecular Biology* **(2005)** http://www.iubmb.org/index.php?id=155&0

U.S. National Academy of Sciences: *Globalization, Biosecurity, and the Future of the Life Sciences* **(2006)** http://www.nap.edu/catalog.php?record_id=11567

[12] Information about the full range of activities related to biosecurity at the U.S. National Academies may be found on its updated Biosecurity website: http://www.nationalacademies.org/biosecurity.

Royal Society—IAP—ICSU: Report of the International Workshop on Science and Technology Developments Relevant to the BTWC **(2006)** http://royalsociety.org/Report-of-the-international-workshop-on-science-and-technology-developments-relevant-to-the-BTWC/

International Union of Microbiological Societies (IUMS): *IUMS Code of Ethics against Misuse of Scientific Knowledge, Research and Resources* **(2006)** http://www.iums.org/about/Codeethics.html

Royal Netherlands Academy of Arts and Sciences: *A Code of Conduct for Biosecurity* **(2007)** http://www.knaw.nl/publicaties/pdf/20071092.pdf

International Union of Pure and Applied Chemistry (IUPAC): *Impact of Scientific Developments on the Chemical Weapons Convention* **(2007)** http://media.iupac.org/publications/pac/2008/pdf/8001x0175.pdf and *Multiple Uses of Chemicals* **(2007)** http://www.iupac.org/publications/ci/2007/2906/pp2_2005-029-1-050.html

Polish Academy of Sciences: *The Advancement of Science and the Dilemma of Dual Use: Why We Can't Afford to Fail* **(2007)** http://www.english.pan.pl/index.php?option=com_content&view=article&id=236:international-conference-on-dual-use&catid=57:archive&Itemid=88

Israel National Security Council and the Israel Academy of Sciences and Humanities: *Biotechnological Research in an Age of Terrorism* **(2008)** http://www.academy.ac.il/asp/about/reports_show.asp?report_id=48

Royal Society: *Royal Society Activities on Reducing the Risk of the Misuse of Scientific Research* **(2008)** http://royalsociety.org/Royal-Society-activities-on-reducing-the-risk-of-the-misuse-of-scientific-research/

French Academy of Sciences: *Les Menaces Biologiques—Biosécurité et Responsabilité des Scientifiques* **(2008)** http://www.academie-sciences.fr/publications/rapports/rapports_html/rapportPUF_Korn.htm

Uganda National Academy of Science: *Promoting Biosafety and Biosecurity Within the Life Sciences: An International Workshop in East Africa* **(2008)** http://ugandanationalacademy.org/downloads/biosafe.pdf

IAP—IAMP—IUBMB—International Union of Biological Sciences (IUBS)—IUMS—Hungarian Academy of Sciences: *The 2nd International Forum on Biosecurity: Summary of an International Meeting* **(2008)** http://www.nap.edu/catalog.php?record_id=12525

Chinese Academy of Sciences—IAP—OECD: *Workshop on Biosecurity* **(2008)** http://english.im.cas.cn/ns/es/200908/t20090826_34257.html

Uganda National Academy of Sciences: *Establishing and Promoting Standards and Good Laboratory Practice (GLP) for Running Safe, Secure, and Sustainable Laboratories in Africa* **(2009)** http://ugandanationalacademy.org/about.htm

Royal Society—International Council for the Life Sciences: *New Approaches to Biological Risk Assessment* **(2009)** http://royalsociety.org/New-approaches-to-biological-risk-assessment/

U.S. National Academy of Engineering: *Ethics Education and Scientific and Engineering Research: What's Been Learned? What Should Be Done?: Summary of a Workshop* **(2009)** http://www.nap.edu/catalog.php?record_id=12695

U.S. National Academies of Science and Engineering—Royal Society—OECD: *Opportunities and Challenges in the Emerging Field of Synthetic Biology: A Symposium* **(2009)** http://sites.nationalacademies.org/PGA/stl/PGA_050738

IAP—IUBMB—IUMS—BEP—Polish Academy of Sciences: *Workshop on Promoting Dual Use Education in the Life Sciences* **(2009)** http://dels.nas.edu/bls/warsaw/

Uganda National Academy of Sciences *The Scope of Biosafety and Biosecurity in Uganda: Policy Recommendations for the Control of Associated Risks*. A Consensus Study Report **(2010)** http://ugandanationalacademy.org/downloads/Scope%20of%20Biosafety%20and%20Biosecurity.pdf

IAP—IUBMB—IUMS—Chinese Academy of Sciences – U.S. National Academy of Sciences: *Trends in Science and Technology Relevant to the Biological Weapons Convention: An International Workshop* **(November 2010)**

REFERENCES

AAAS (American Association for the Advancement of Science). 2008. *Professional and Graduate-Level Programs on Dual Use Research and Biosecurity for Scientists Working in the Biological Sciences: Workshop Report*. Washington, DC: American Association for the Advancement of Science. Available at http://cstsp.aaas.org/files/AAAS_workshop_report_education_of_dual_use_life_science_research.pdf.

BMA (British Medical Association). 1999. *Biotechnology, Weapons and Humanity.* London: Harwood Academic Publishers.

BWC (Biological and Toxin Weapons Convention). 1986. Second Review Conference of the States Parties to the Biological Weapons Convention. Final Document. Geneva: Biological Weapons Convention.

BWC. 2005. Report of the Meeting of the States Parties. Geneva: United Nations.

BWC. 2006. Sixth Review Conference of the States Parties to the Biological Weapons Convention. Final Document. Geneva: Biological Weapons Convention.

BWC. 2008. Report of the Meeting of States Parties. Geneva: United Nations.

FASEB (Federation of American Societies in Experimental Biology). 2009. Statement on Dual Use Research and Biosecurity Education. Bethesda, MD: FASEB. Available at http://www.faseb.org/Policy-and-Government-Affairs/Science-Policy-Issues/Homeland-Security-and-Visas.aspx.

IAP. 2005. Statement on Biosecurity. Available at http://www.interacademies.net/CMS/About/3143.aspx.

NRC (National Research Council). 2004a. *Biotechnology Research in an Age of Terrorism*. Washington, DC: National Academies Press.

NRC. 2004b. *Seeking Security: Pathogens, Open Access, and Genome Databases*. Washington, DC: National Academies Press.

NRC. 2006. *Globalization, Biotechnology, and the Future of the Life Sciences*. Washington, DC: National Academies Press.

NRC. 2009d. *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: National Academies Press.

NRC. 2009f. *2nd International Forum on Biosecurity: Report of an International Meeting, Budapest, Hungary, March 30-April 2, 2008*. Washington, DC: National Academies Press.

NSABB (National Science Advisory Board for Biosecurity). 2007. Proposed Framework for the Oversight of Dual Use Life Sciences Research: Strategies for Minimizing the Potential Misuse of Research Information. Available at http://www.biosecurityboard.gov/news.asp.

NSABB. 2008b. Charter (Revised March 28, 2008). Available at http://oba.od.nih.gov/biosecurity/PDF/NSABB_Charter_508_accessible.pdf.

Rappert, B. 2004. *Towards a Life Science Code: Countering the Threats from Biological Weapons.* Bradford Briefing Paper No. 13, September. Available at http://www.brad.ac.uk/acad/sbtwc.

Rappert, B., M. Chevrier, and M. Dando. 2006*. In-Depth Implementation of the BTWC: Education and Outreach*. Bradford Review Conference Paper 18. Available at http://www.brad.ac.uk/acad/sbtwc/briefing/RCP_18.pdf.

Rocca, C. 2008. Statement by H.E. Ambassador Christina Rocca, U.S. Representative to the Biological Weapons Convention, to the Annual Meeting of the Biological Weapons Convention States Parties, Geneva, Switzerland, December 1, 2008.

Royal Society. 2002. Submission to the Foreign and Commonwealth Office Green Paper on Strengthening the Biological and Toxin Weapons Convention. Available at http://royalsociety.org/Submission-to-FCO-Green-Paper-on-strengthening-the-Biological-and-Toxin-Weapons-Convention/.

Royal Society. 2004. Do No Harm—Reducing the Potential for the Misuse of Life Science Research. Available at http://www.wellcome.ac.uk/stellent/groups/corporatesite/@policy_communications/documents/web_document/wtx023408.pdf.

Appendix D

Discussion Questions for Breakout Sessions

Questions for Session #1

1. What is the current extent of dual use education and "values education" in the life sciences internationally? In general are researchers aware of the concept of dual use research and "dual use research of concern"?
2. Where is dual use education for life scientists being introduced? Likely candidates include bioethics, responsible conduct of research training, and biosafety. What are the advantages (and disadvantages) of including dual use in each? What successes and failures have come as these programs have been carried out?
3. What is the range of resources currently available to support dual use education and what gaps currently exist?

Questions for Session #2

1. What can we learn from research on education and from experience in developing approaches and educational materials? Which pedagogical approaches, strategies and types of materials are likely to be most effective at enhancing awareness? At generating and sustaining interest and attention?
2. What types of educational models and approaches have been used and why were these approaches selected over others? How were these approaches developed? What methodology are they based

on? What approaches were proposed or considered but not implemented? Which approaches have not worked?

3. How should we move forward on developing and implementing educational approaches to dual use education? How can the implemented educational activities be designed to promote life science while mitigating misuse and risks to security? Who should be involved?
4. How can we tell if the approaches and materials are having the desired impact? How will we assess the effectiveness?

Questions for Session #3

1. Building on Breakout Session #1 how can dual use education and concepts be better integrated into the life sciences community (e.g., in training programs, institutional activities, etc.)? How can successful models be sustained over time?
2. What opportunities are there for additional work in the education area? How can it be accomplished in a collaborative manner, and in particular can it be accomplished on national, regional, and global scales? How can successful models be promoted and how can the importance of dual use education best be disseminated to others?
3. What have been the barriers, challenges, or hurdles to addressing the dual use research issue? How have these challenges been met or overcome? What challenges remain? Is there anything that could have been done differently in implementing any of these approaches to have made them more successful
4. How can we tell if the approaches and materials are having the desired impact? How will we assess the effectiveness?