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Implementing Biosecurity Education: Approaches, Resources and Programmes

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Abstract

This paper aims to present possible approaches, resources and programmes to introduce the topic of biosecurity to life scientists and engineers at the higher education level. Firstly, we summarise key findings from a number of international surveys on biosecurity education that have been carried out in the United States, Europe, Israel and the Asia–Pacific region. Secondly, we describe the development of our openly-accessible education resource, illustrating the scope and content of these materials. Thirdly, we report on actual cases of biosecurity education that have been implemented. These include achievements in and lessons derived from the implementation of biosecurity education at the National Defense Medical College in Japan. These experiences are followed by presentation of the expert-level "Train-the-Trainer" programmes subsequently launched by the University of Bradford in the United Kingdom. These examples will help readers to understand how educators can enhance their own understanding about biosecurity issues and how they can then disseminate their knowledge through development of their own customised, relevantly-targeted and stage-tailored education programmes within their own life science communities. By providing these examples, we argue that education for life scientists, policy-makers and other stakeholders about social responsibility on dual-use issues is easily achievable and need not be expensive, time-consuming or over-burdening. We suggest that recurring classes or courses be held at appropriate times during educational programmes to accommodate the developing expertise and advancing learning stages of students.

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Introduction

Biotechnology, as part of the life sciences, is one of the most rapidly-growing areas of cutting-edge science and engineering in the early twenty first century. This rapid growth and technological advancement has offered great social benefits globally, for example in improvements to public health, agriculture and energy development. Alongside these benefits, however, the same advances also generate safety and security risks, which, while less obvious, are nonetheless real. International society already manages risks in biotechnology research through the concept of biosafety (World Health Organization 2004). However, in addition to the risks addressed by biosafety containment and engineering safety standards, life science research and engineering developments can also give rise to issues of dual-use, whereby peacefully developed scientific research and engineering projects can be misused for destructive purposes, such as biowarfare and bioterrorism (National Research Council 2004).

A major challenge for today's international community is to find effective ways to raise awareness among scientists about their social responsibility regarding the potential for the destructive use of the life science research in which they are engaged.[1] The life sciences differ from nuclear science developments in that they are conducted around the world in commercial and academic laboratories rather than those belonging to national governments (National Research Council 2006). In addition to this wider scale of practice, the actual speed of scientific advancement and resulting security implications are "possibly too fast for any State, organization or individual to cover alone" (Millet 2010, p. 29). Moreover, there are critical ambiguities surrounding the boundary between defensive and offensive biological programmes[2] which can be used to blur issues of legality (although it is clear under the Biological and Toxin Weapons Convention (BTWC) that the development of all biological weapons is illegal, as is their production, acquisition, transfer, retention, stockpiling and use).[3] Finally, in order to address the concerns of scientists, approaches aiming to promote a culture of biosecurity-based social responsibility need to be mindful to "ensure a focus on the highest-risk research and avoid unnecessary restrictions or censorship" over scientific freedom (Smith et al. 2010, p. 137).

Accordingly, there is a need for better collaboration between scientific communities and policy makers. For this very reason, there is also a need for education specifically designed to better inform scientists' and policy-makers' understanding of how the potential for the

[1]A resource that can support scientists and other stakeholders in the area of social responsibility-awareness is Sture (2010a).
[2]For various ambiguities over the boundary between defensive and offensive biological programmes, see Wright and Ketcham (1990).
[3]The Convention on the Prohibition of the Development, Production and Stockpiling of Bacteriological (Biological) and Toxin Weapons and on their Destruction, commonly known as the Biological Weapons Convention (BWC) or Biological and Toxin Weapons Convention (BTWC). This was the first multilateral disarmament treaty banning an entire category of weapons. It opened for signature in 1972 and came into force in 1975. http://www.unog.ch/80256EE600585943/(httpPages)/04FBBDD6315AC720C1257180004B1B2F?OpenDocument. Accessed 5 May 2011.

misuse of the life sciences and related technologies can be recognised and prevented. In this paper, such efforts to develop a web of preventive policies are broadly envisaged as biosecurity.[4] We suggest that such biosecurity education should incorporate themes such as, *inter alia*, the potential for dual-use risks in contemporary life sciences; the responsible conduct of research and ethical approaches among life scientists; the history of biological-warfare programmes and biological terrorism; the role of international prohibition regimes and their national implementation[5]; the intersection of public health and national security; and the building of an effective set of preventative policies to ensure the security of benign developments in the life sciences.

Increased International Attention—Remaining Lack of Awareness

The necessity of awareness-raising among life scientists about dual-use issues has been underlined by governments and professional communities in science, public health, security and ethics (Miller and Selgelid 2007; Gorski and Spier 2010). These include the Inter-Academy Panel (IAP) (IAP 2005; Nature 2003), the World Health Organization (WHO) (2007), the Organization for Economic Cooperation and Development (OECD) (2007), and the BTWC (2008). However, against such growing international attention towards biosecurity education, the lack of awareness of individual scientists across the globe has been clearly demonstrated (Dando and Rappert 2005; Rappert et al. 2006). Further to this, the limited availability of biosecurity tutoring at the university level has been illustrated by a series of international surveys investigating the current state of biosecurity-related degree courses in the United States (National Research Council 2009a), Europe (Mancini and Revill 2008), Japan (Minehata and Shinomiya 2010), Israel (Minehata and Friedman 2009), and the Asia–Pacific region (Minehata 2010). In the case of Japan, for example, we noted that a range of difficulties were faced by university lecturers in introducing appropriate teaching due to:

- an absence of space in existing curricula;
- an absence of time and resources available to develop new curricula;
- an absence of expertise and available literature on biosecurity education; and
- general doubt and scepticism about the need for biosecurity education on the part of educators and scientists (Minehata and Shinomiya 2010).

Despite these commonly experienced obstacles, our surveys indicated the possibility of promoting biosecurity education by utilising already-implemented ethics education processes. We found that a large number of universities surveyed already have educational modules focusing on ethics. Therefore, we recommended an expansion of the scope of traditional ethics education by integrating the concept of dual-use biosecurity as part of the education in social responsibility already offered to life scientists (National Research Council 2009a; Revill et al. 2009).

[4]There have been efforts to conceptualise a multifaceted approach comprising several practical measures through what is termed the Web of Prevention (WoP). For the conceptual evolution of the WoP in literature, see Feaks et al. (2007).
[5]Such as BTWC of 1972, Chemical Weapons Convention of 1993 or Geneva Protocol of 1925.

Development of Education Materials

What kind of educational material can be of use in the absence of widespread expertise and available literature on biosecurity education? One answer is to place open-source teaching materials online, via the internet.[6] There are a number of benefits to this approach. Firstly, it is important to recognize that there is no "one-size-fits-all" answer to biosecurity education. Secondly, there are significant differences in priorities between academic institutions, national and regional needs and also variations derived from differing socio-cultural backgrounds. Because of these distinctions, online educational resources are useful, as they can be modified and tailored by users in order to fit the specific teaching modes and needs in various local educational contexts. Further, they ease pressures on time spent in planning and preparing material, overcome financial constraints on the development of biosecurity curricula, and provide the expertise required for efficient and effective assimilation of such material (Dando 2008). In addition, tutors are free to choose what to include in sessions and at what level to "pitch" their teaching, depending on the educational level and technological perspectives of the audience.

To illustrate this, we can look at recent work by the University of Bradford in conjunction with the National Defense Medical College (NDMC) in Japan and the Landau Network Centro Volta in Italy. This collaboration led to the recent launch by the University of Bradford of an online Educational Module Resource (EMR) to assist university-level lecturers to incorporate material on biosecurity and dual-use issues into their life science courses at a higher education level (University of Bradford & National Defense Medical College 2008). This EMR is freely available online and may be used and adapted by any interested individual or group. It is currently available in English, Japanese, Russian and Romanian. It will shortly be available in Urdu, French, Moldovan and other languages. It offers a brief but comprehensive history of the BTWC and covers Dual-Use Bioethics, National Implementation of the BTWC and different levels of preventive policies that address the potential for the destructive use of the life sciences (University of Bradford 2011).

Following on from the use of this type of educational resource, the next stage in promoting biosecurity education is to build education capacity through the implementation of similar modules in different academic contexts and institutions. This will disseminate knowledge and understanding more broadly and is likely to engage a wider range of students, educators and scientists as it is implemented.

Introduction of Online Materials as Part of Academic Curricula

By using the EMR, biosecurity education programmes have been provided at the NDMC since October 2008 both at the undergraduate and postgraduate levels. Table 1 summarises the scope of both programmes.

[6]The Federation of American Scientists lists many stand-alone online educational materials by various institutions and educational programmes at universities. See Virtual Biosecurity Center (VBC). http://www.fas.org/programs/ssp/bio/educationportal.html. Accessed 5 May 2011.

We argue that the breadth and depth of education should correspond to the knowledge and experiences of students. At NDMC we start biosecurity education in the third year, providing a brief introduction and drawing students' attention to the concept of biosecurity. By the sixth (final) year, students have a deeper knowledge about medical issues; we educate them at that point with specific examples about dual-use dilemmas in medical science. In order to further strengthen students' motivation to become good physicians as well as responsible scientists, we require graduating students to take the Hippocratic Oath.

The timing of the implementation of biosecurity education should be carefully considered. At the NDMC (Table 1), the undergraduate programme biosecurity intervention takes place just prior to the graduation ceremony but immediately after the national examination for accreditation as a medical practitioner. This timing was specifically targeted to effectively inform students about their social responsibility just prior to becoming qualified medical professionals on graduation from the College. Subsequently, the postgraduate biosecurity education programme is placed immediately after the registration as a doctoral student in order to remind students of their professional responsibility before beginning to practice advanced scientific and technological research. Such an approach appears to be effective, and is supported by evidence from a number of US medical schools which showed that carefully and appropriately-timed ethics teaching (also a form of social responsibility education) was more effective than one-off "tick-box" approach sessions at the beginning of undergraduate programmes. These medical schools found that by presenting students with ethics teaching that was directly related to their stage of education, the uptake and understanding of the issues were improved (Sture 2010b).

The NDMC education programme in 2008 involved a 5 day course for 19 postgraduate students at the beginning of their degree in Medicine (Table 2). This process was repeated using similar content for 57 medical students at the end of their six year curriculum in 2009 at the undergraduate level. Both undergraduate and postgraduate programmes have been further developed in 2010 and 2011 based on response from students and lessons learned. For materials on the BTWC (Table 2), the Bradford online education material (EMR) was used by NDMC lecturers, who modified the original EMR content to suit the academic requirements of the College. As medical doctors and researchers, students at NDMC are life scientists, while at the same time being members of Japan's Self-Defense Force (SDF); their educational topics are therefore differently designed from those adopted in other life science degree courses in Japan. This illustrates the importance of developing specific educational material for specific educational programmes, but shows at the same time how this can be achieved with relative ease.

The basic themes (science, ethics and security) of the undergraduate programme are the same as those at the postgraduate level. The topics in Table 2 are also included in the undergraduate programme but with fewer hours' coverage for each topic in order to fit them into a two-day course. The undergraduate programme has a greater focus on the socially-mediated aspects of biosecurity issues, such as the history of bioweapons programmes and of the BTWC. This is because students in the earlier stages of their science education have not yet fully developed their technical expertise, making it more useful to engage them with dual-use issues through a historical approach in the first instance.

By contrast, at the post-graduate level the NDMC biosecurity education programme has been more intensively designed, comprising a 5-day course with the inclusion of possible cases of dual-use research and the consideration of practical preventive solutions, including the provision of national legislation (Yamada 2011). Bearing in mind student limitations (their progress in terms of scientific education and their sense of professional responsibility), we find that it is vital to present real life examples of dual-use problems, in order to persuade audiences effectively of the reality of the risks inherent in everyday scientific work.

To clarify and ascertain students' understanding of the content of this course, tests were conducted, covering the whole range of taught topics, using multiple choice questions. As an interactive learning process, open-ended questions were also provided to allow students to freely offer their views in the feedback and discussion sessions at the end of the programme.

For example in 2008, 29 multiple choice questions were provided (Fig. 1). Question numbers covers the topics of Table 2 as follows: numbers 1–3 (Life Science and Ethics); 4–6 (Intellectual Property); 7–10 (Codes of Conduct for Life Scientists); 11–14 (Dual-use Dilemma); 15–17 (BTWC); 18–19 (Present Status of Biosafety); 20–22 (Biosecurity: Research Fields of Concern); 23–25 (Context: Scientists and Scientific Papers); 26–29 (Ethics for Animal Experiments: Basic Rules and Legislation). As we can see, students answered the topics relatively well in general, although some questions turned out to cause difficulties, resulting overall in a dispersed range of correct answers.

Finally, an anonymous questionnaire was circulated to the NDMC students to check the accessibility of each taught topic in this educational process by asking "Was your understanding of the following aspects of the module developed?" A score of five indicated the highest positive mark and one, the lowest. Figure 2 indicates how students assessed the understanding of the taught topics through the educational programme. We were pleased to recognise that students evaluated the utility of the programme positively.

As different research and academic institutions have different research objectives, what constitutes an area of dual-use concern for practicing scientists is significantly different from place to place and discipline to discipline. A further lesson from NDMC was the recognition of the importance of targeting appropriate educational topics at different levels of audience. For example, some highly advanced dual-use research examples were not successfully understood by earlier-stage undergraduate students as their scientific background was not sound enough at that point. In such cases, even if the examples given are very familiar to security experts, student engagement is reduced.

This again echoes the experiences of US medical schools in delivering effective ethics education to medical students (Sture 2010b). However, the ethical responsibilities of scientists and the various historic illustrations of past biological weapons programmes were relatively well understood by early-stage NDMC undergraduates who showed significant interest. Although the development of understanding can be tracked and evaluated through a combination of the examination (Fig. 1) and the questionnaire (Fig. 2), the assessment of the effectiveness of the course could be further developed, for example by introducing pre-

course questionnaires in addition to post-course questionnaires. In addition, further evaluative work could, and should, include one-to-one interviews with students about their thoughts and experiences about the courses and the issue of biosecurity education itself.

The Bradford Online Train-the-Trainer Programme

Alongside the education of young scientists at the higher education level, the Bradford Train-the-Trainer programme is another important addition to the global agenda. Early results and feedback from this programme appear to indicate that this is one of the most efficient and effective ways in which to build a worldwide sustainable capability in dual-use biosecurity (University of Bradford 2011). Such courses can be delivered online using interactive virtual learning platforms where course participants can explore, in real-time, through face-to-face lectures, issues of relevance to dual-use and biosecurity; importantly, they can also address actual concerns and dilemmas that result from real-life situations that are known to have occurred in the life sciences. We find, to date, that any variations in levels of scientific understanding and/or professional responsibilities that may be present among the class members at the beginning of the course appear to be ameliorated by the length of the course and the *amount* of learning that takes place over the extended period of time taken by the programme.

With the aid of such teaching technologies, life scientists can usefully engage in discussions about the concept of biosecurity. Through discussions, Bradford Train-the-Trainer participants are required to assess and consider the ways in which the broader term ‘biosecurity’ relates to (but differs from) the concept of laboratory biosecurity and the management of biosecurity risks which have arisen in the process of ensuring that dangerous materials are kept secure from those with malign intent. Engagement with the issue of ‘biosecurity’ (rather than ‘biosafety’) can facilitate the development of a more broadly-informed appreciation of the term as it used to relate to a threat spectrum that ranges from natural and accidental outbreaks of disease, through to deliberate outbreaks of disease. It can be illustrated through teaching that natural outbreaks of disease are addressed by public-health measures, and accidental outbreaks of disease by ‘biosafety’ measures—in other words by addressing seriously all issues around good laboratory practice. The concept of biosecurity is therefore clearly placed in relation to deliberately-caused outbreaks of disease, and is shown to relate to many activities beyond the laboratory door as well as within the laboratory itself. Thus biosafety and laboratory biosecurity can be viewed by life scientists as component parts of a wider concept of biosecurity (Whitby and Dando 2010).

Train-the-Trainer online learning courses can therefore be designed to include a range of learning outcomes. They may offer these by:

- Introducing participants to the wider concept of ‘biosecurity’;
- Introducing participants to the concept of ‘bioethics’ and its relationship to the broader issue of biosecurity;
- Developing scientists’ and stakeholders’ awareness and understanding of a range of dual-use ethical dilemmas that arise due to the impact of science and technology on society;

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- Developing scientists' and stakeholders' knowledge of ethical approaches which provide a rationale for ethical decisions or recommendations regarding dual-use technologies;
- Facilitating further ethical research into dual-use issues and developing policies and practices that will prevent the misuse of knowledge generated through biomedical research;
- Encouraging participants to bring their own personal ideas and experiences to the course and to share ideas with their fellow participants in order to contextualise knowledge, recognise and understand ways that will help meet the ethical challenges posed by dual-use;
- Allowing participants on such courses to engage with online lectures, seminars, discussion groups and interactions on course-work-related topics, involving tutors, moderators and students;
- Enabling participants to benefit from a supportive and interactive on-line web-based learning community as they approach the completion of coursework assignments and the completion of online group work presentations based on real-world dual-use life science scenarios;
- Facilitating participants in the development of their own education programmes at their own research/academic institutions, focusing on a broader scope of biosecurity issues, by supporting life scientists in the use of the EMR.

As described above, the EMR is a freely-available and openly-accessible teaching resource on biosecurity issues. On the other hand, the Train the Trainers programme is a university-accredited educational course that aims to create experts who can improve the utility of the existing EMR. Both provisions (the educational resource and the educational course) therefore mutually reinforce each other.

Lectures can be designed to address the themes identified above (web of prevention policies and activities along with biosecurity issues) as being of central importance to the development of an informed appreciation of biosecurity. This will ensure coverage of a range of issues of relevance including an understanding of: the threat (offensive biological warfare programmes and bioterrorism); the prohibition regimes (the Geneva Protocol, the BTWC, the Chemical Weapons Convention, Security Council Resolution 1540); dual-use dilemmas (including paradigm cases such as Mousepox, Spanish Influenza, and Synthetic Polio); the responsible conduct of research *On Being a Scientist* (National Research Council 2009b); the importance of national implementation of the BTWC; and, the wider web of preventative policies that together minimise the risk of the hostile misuse of biotechnology and other life science work (University of Bradford 2011).

A case study approach, applied in seminar scenarios, can usefully allow life scientists to develop an informed appreciation of the range of dual-use dilemmas; knowledge and learning can be enhanced in this respect by inviting disclosure of direct personal experience of dual-use dilemmas that participants may have been confronted with in either educational settings or in the workplace. Advanced-level group work seminar scenarios can be designed

with practical application in mind, for example, by setting an assignment that invites participants to show how they might utilise the information in the EMR through its incorporation and assimilation into their teaching of others across a range of educational and professional settings.

We recognise that our own experience in Bradford has shown that education delivered as a programme over a number of weeks appears (anecdotally as yet) to be more effective than one-off classes in producing changes in behaviour and perspective among participants.

Conclusion

This article has demonstrated that biosecurity education is easily manageable if efforts to introduce it are successfully backed up by the development of effective educational resources, definition of the target audience and a determination to implement it at the appropriate level of scientific education and professional responsibility. We believe that the introduction of scientists to the risks of dual-use is the key first step in such education. Our work so far appears to suggest that students' understanding of issues may advance in proportion to their scientific education level and/or their level of professional responsibility. Students have developed a depth of understanding of dual-use issues in relation to their own field, and have also gained a breadth of understanding beyond this into other fields. By building capacity in this way amongst groups of informed life scientists, we believe that the existing web of preventive policies will be naturally strengthened.

We have shown that "one size will not fit all countries" or even all institutions, and we have illustrated our argument with an example of institution-specific materials and resources that have been developed to accommodate this. In addition to the examples we have given here, it has also been reported that the implementation of such resources at different academic institutions has been taking place internationally although the number is limited (National Research Council 2010).

For the next step, what is really needed to mitigate against a slow advance in the spread and uptake of international biosecurity education is the development of an international network to share emerging best practice.[7] Currently, international efforts to advance education on dual-use issues have only been developed by individual academic institutions, i.e. efforts to date have been mainly 'bottom-up'. In order to further advance the agenda, 'top-down' efforts to provide a structural change in the education culture of the life sciences are also needed. For this purpose, the high-level engagement of governments with coordinated policy decisions is essential.

In a move towards such governmental engagement, the States Parties of the BTWC in 2008 recognised the utility of introducing dual-use education for life scientists including "possible mandatory components" (United Nations 2008, pp. 6–7). This call required the implementation of dual-use education within certain types of life science degree courses at

[7]Landau Network Centro Volta in Italy has been promoting biosecurity education in European countries and organising wide range of workshops. See Landau Network Centro Volta. http://www.centrovolta.it/landau/2009/12/10/PromotingSustainableEducationAndAwarenessRaisingOnBiosecurityAndDualUse.aspx. Accessed 5 May 2011.

universities. The process of reporting back on the implementation of biosecurity education through such an international framework as the BTWC is vital to provide credibility to individual activities and to share relevant experience across academic institutions and countries.

The Seventh Review Conference of the BTWC is due to take place in December 2011.[8] This will be a major opportunity for the international community to advance the topic of education as a high priority. Firstly, efforts need to concentrate on the facilitation of the implementation of biosecurity education at different academic institutions. Secondly, efforts are needed to encourage the formalisation of further international frameworks to discuss and promote the enhancement of dual-use and biosecurity awareness among scientists. Rappert (2010) has suggested that such formalisation may include:

- The establishment of international state co-ordinators and/or regional coordinators,
- The organisation of continued international workshops to share best practice,
- Provisions of bilateral and multilateral assistance,
- Greater incorporation of civil society organisations into the BTWC,
- Yearly reporting of activities.

It is to be hoped that academic institutions, educators and practising scientists will engage effectively with this issue. We have shown here the relative ease with which biosecurity education may be implemented and that it need not be expensive, time consuming or onerous in terms of workload. By engaging with biosecurity education, we can play a significant part in the formation of the next generation of scientists in whose hands the future wellbeing of society may well be assured.

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[8]Since 1980, Review Conferences have taken place once every 5 years and the next Review Conference will take place in December 2011.

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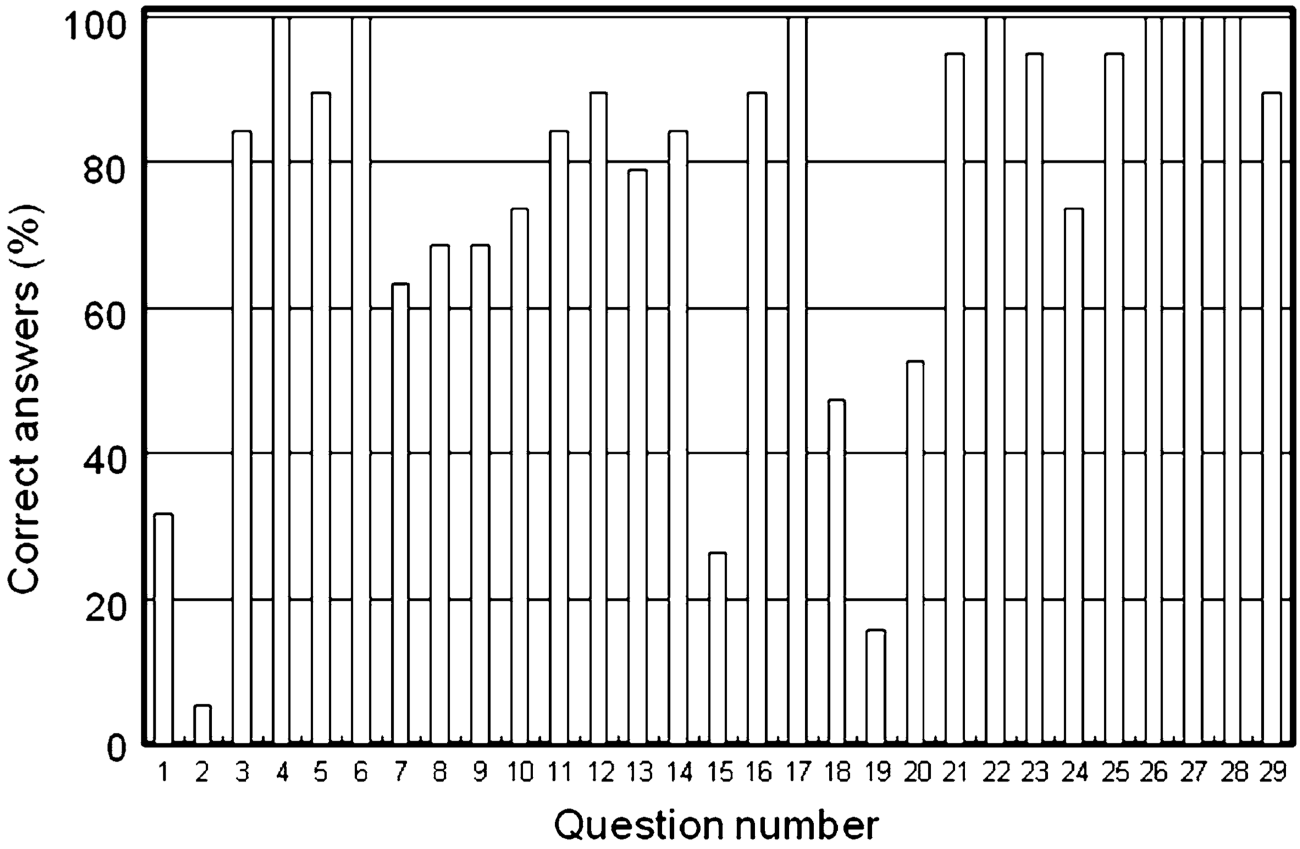

Fig. 1.
Results of post-course examination

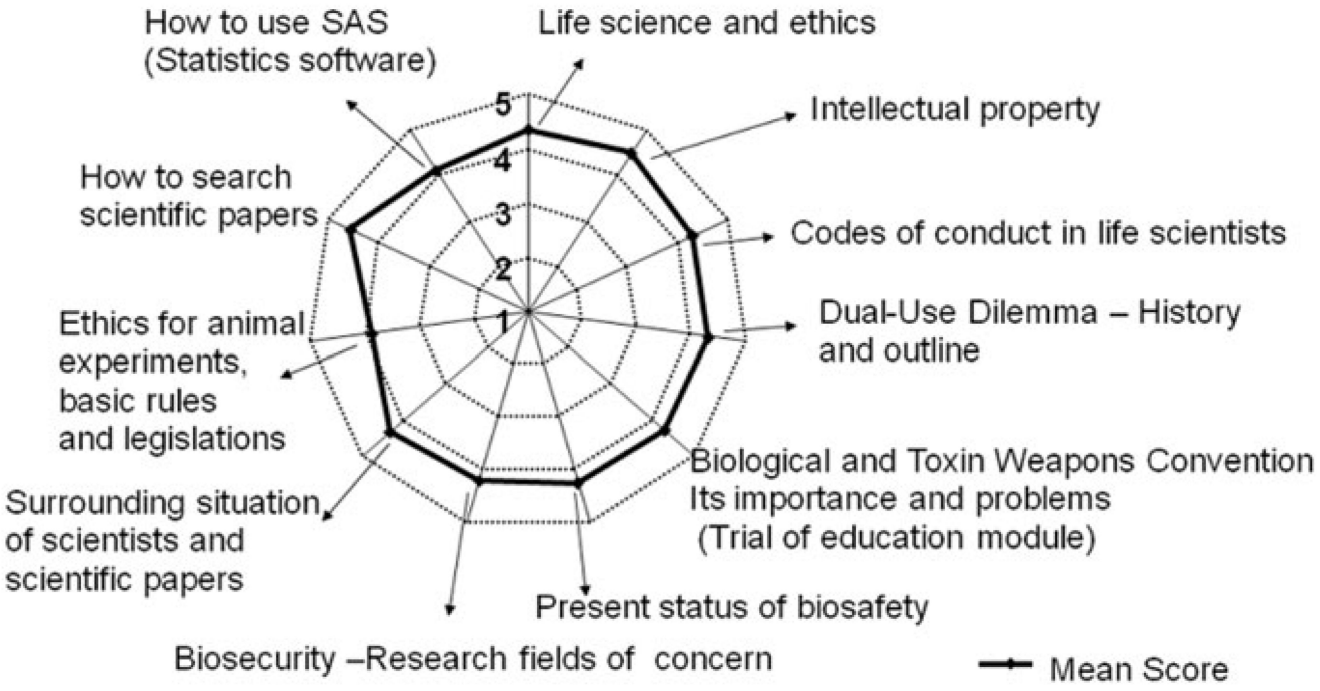

Fig. 2.

Mean score derived from student questionnaire on the NDMC module. *Source* Shinomiya (2008)

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Table 1

Outline of the biosecurity education programmes at the NDMC

	Undergraduate 6 year (MD)	**Postgraduate 4 year (PhD)**
Objective	To give an introductory picture of dual-use issues and the social responsibilities of a medical doctor	To solicit active consideration of dual-use issues as a practicing scientist in advanced research projects
Timing	Just prior to the graduation ceremony (including the Hippocratic Oath)	Immediately after the registration as a PhD candidate
Duration	2 days	5 days
Assessment	Examination and scenario-based discussion	Examination and scenario-based discussions

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Table 2

Outline of NMDC dual-use biosecurity education: graduate programme

Day	Time	Topic
Day 1	09:00–09:15	Introduction
	09:15–10:45	Life science and ethics
	11:00–12:00	Intellectual property
Day 2	09:00–09:45	Codes of conduct for life scientists
	09:45–10:30	Dual-use dilemma: history and outline
	10:45–11:30	Biological and toxin weapons convention (BTWC)
	11:30–12:00	Present status of biosafety
Day 3	09:00–09:50	Biosecurity: research fields of concern
	09:50–10:40	Context: scientists and scientific papers
	10:50–12:00	Ethics for animal experiments: basic rules and legislation
Day 4	09:00–10:00	How to search scientific papers
	10:10–11:20	How to use statistical analysis systems (SAS)
	11:20–11:50	Examination
	13:00–14:30	Guidance in core facilities
Day 5	09:00–10:00	Feedback and discussion 1
	10:10–11:20	Feedback and discussion 2
	11:20–11:50	Closing remarks

Source: Minehata and Shinomiya (2010)