Biosafety and Health 4 (2022) 339–346

Contents lists available at ScienceDirect

Biosafety and Health

journal homepage: www.elsevier.com/locate/bsheal

Key issues in the implementation of the Tianjin Biosecurity Guidelines for Codes of Conduct for Scientists: A survey of biosecurity education projects

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ARTICLE INFO

Article history:
Received 22 June 2022
Revised 28 July 2022
Accepted 23 August 2022
Available online 28 August 2022

Keywords:
Tianjin Biosecurity Guidelines
Biosecurity education
Survey
Biological and Toxin Weapons Convention (BTWC)

ABSTRACT

In order to effectively implement the *Tianjin Biosecurity Guidelines for Codes of Conduct for Scientists*, biosecurity awareness-raising and education are essential because if these are not in place scientists will not understand the need for biosecurity codes of conduct. In an effort to assist in the implementation of the guidelines, a small-scale survey was carried out in early 2022 of biosecurity awareness-raising and education projects that have been developed over the last two decades to discover what resources and experience have been accumulated. It is argued that the survey demonstrates that much of what is needed to implement the guidelines effectively has been developed, but that there are specific deficiencies that need to be remedied quickly. In particular, an updated teaching resource covering the core issues related to the Biological and Toxin Weapons Convention (BTWC) and the problem of dual use in scientific research needs to be made widely available and translated into at least the six official United Nations (UN) languages. Additionally, more specialists from the Humanities with expertise in ethics need to become involved in biosecurity awareness-raising and education activities. While advantage should be taken now of the available national, regional and international networks of people involved in related activities, it is suggested that in the longer term cooperation in biosecurity awareness-raising and education will benefit from the development of an equivalent organisation to the International Nuclear Security Education Network (INSEN) organised through the International Atomic Energy Agency (IAEA).

1. Introduction

The coronavirus disease 2019 (COVID-19) pandemic has re-emphasized the need for greater attention to be paid to biological safety and biological security [1]. In that regard, particular attention will need to be paid to strengthening the chemical and biological disarmament and non-proliferation regimes embodied in the Chemical Weapons Convention (CWC) and the Biological and Toxin Weapons Convention (BTWC) [2]. Recent work, for example by the World Health Organisation (WHO) [3], has pointed out that improvements are needed in the tools and mechanisms available to stakeholders at all levels including individual scientists, their professional organisations and their institutions. Thus, there has been increasing interest in the development of codes of conduct for life scientists as a contribution to the overall strengthening of biosecurity [4,5].

At the meeting of the States Parties to the BTWC in late 2021, China and Pakistan presented a Working Paper, co-sponsored by Brazil, titled *The Tianjin Biosecurity Guidelines for Codes of Conduct for Scientists* [6]. These States Parties argued that "Broad acceptance of responsible biological research and development of corresponding codes of conduct will bring out the full potentials and benefits of research in this field and help to prevent its misuse and abuse." The Guidelines consisted of ten elements: Ethical Standards, Laws and Norms, Responsible Conduct of Research, Respect for Research Participants, Research Process Management, Education and Training, Research Findings Dissemination, Public Engagement on Science and Technology, Role of Institutions, and International Cooperation.

These Guidelines came with the endorsement of the InterAcademy Partnership (IAP) of National Scientific Academies and after long consideration by States Parties to the BTWC that had begun in 2005. It was not surprising therefore that the summary of the 2022 meeting [7] noted that "many States Parties expressed support for the Tianjin Biosecurity Guidelines.".

Significantly, the Working Paper presented by China and Pakistan ended with proposal that the Nineth Review Conference:

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https://doi.org/10.1016/j.bsheal.2022.08.003
2590-0536/

HIGHLIGHTS

Scientific question

Implementation of the Tianjin Guidelines is a critical component in efforts to improve biosecurity. Implementation is unlikely without major improvement in biosecurity education of life scientists. This paper presents a survey of biosecurity education projects over the last two decades.

Evidence before this study

Biosecurity education projects occurred from 2005 when codes of conduct discussion began in BTWC meetings. Some biosecurity education projects were reported in detail by States Parties in BTWC meetings. However, few attempts had been made to analyse what had been done within the different projects.

New findings

This study remedies that gap by use of a systematic questionnaire on biosecurity education projects. The questionnaire had a set of 21 questions, and we received 26 replies from projects around the world. This report is the first to provide such a systematic survey of biosecurity education projects. It provides a review of measures available to improve biological security education globally.

Significance of the study

The study provides a first analysis of the diverse biosecurity education resources that have been developed and tested. That knowledge will assist in the development of biosecurity education worldwide.

> "(a) Endorse the Tianjin Guidelines and encourage all stakeholders to voluntarily incorporate elements from the Guidelines in their practices, protocols, and regulations, and to disseminate the Guidelines, as appropriate, and
>
> (b) Task the intersessional process to exchange information, experiences, and good practice about the dissemination of the Tianjin Guidelines and report the outcomes of these exchanges and dissemination to the Tenth Review Conference."

We think that these are important proposals, and considering the support given to the Tianjin Guidelines from many States Parties, we would expect that such measures for the implementation of the Guidelines would also find strong support at the Review Conference. However, we would argue that not all of the elements of the Tianjin Guidelines are equivalent in relation to their successful implementation into effective operational codes of conduct that can affect the behavior of life scientists. In particular, we would point out the key significance of Element 6 of the Guidelines on *Education and Training* that reads:

> "Scientists, along with their professional associations in industry and academia, should work to maintain a well-educated, fully trained scientific community that is well versed in relevant laws, regulations, international obligations, and norms…. to provide a more robust understanding of the implications of biological research…"

It has often been assumed [8] that the process of producing codes "raises awareness amongst the target groups and fosters discussion on the potential for misuse of life science research." That is to say, the development of codes of conduct produces awareness – which unfortunately is to "put the cart before the horse" because as Australia noted [9] during the original discussion of codes of conduct in 2005:

> "1. *Amongst the Australian scientific community, there is a low level of awareness of the risk of misuse of the biological sciences to assist in the development of biological or chemical weapons*. Many scientists working in 'dual-use' areas simply do not consider the possibility that their work could inadvertently assist in a biological or chemical weapons programme. For most of these researchers, biological weapons issues may seem irrelevant and therefore *strong advocacy is required to overcome natural resistance or ignorance*. Introducing Codes of Conduct that highlight these issues is an important step in raising awareness. However, *it is not enough simply to put such Codes in place. Without effective measures to educate scientists about the existence and importance of such Codes, attitudes and awareness will remain largely unchanged.* "(Emphases added)

So, without making sure that scientists understand the need for a biosecurity code of conduct it is unlikely that any such code will be implemented effectively. For this reason, considerable effort has been put in by many States Parties to improve the education and awareness of life scientists about the dangers of dual use and biosecurity more generally [10–12], but it has proven very difficult to shift the culture of the life science community [13] towards biosecurity. Despite such efforts [14], novel means of active learning [15,16] and innovative means of awareness-raising [17] are clearly needed to shift-long held perspectives and appreciations.

Therefore, it is not surprising that whilst we do not have systematic reviews of the evidence, all of the anecdotal evidence we have seen strongly suggests that there has *not* been a significant improvement in the knowledge of the problems of dual use and biological security in general amongst the life science community since the Australian opinion in 2005 [18]. Moreover, difficulties in raising awareness and improving biosecurity education are only likely to increase as the huge number of scientists practicing in the life and associated sciences continues to grow all around the world. It therefore seemed useful, in order to assist with the implementation of the Tianjin Guidelines, to attempt to assess the resources that have been developed through biosecurity education and awareness-raising projects over the last two decades prior to the 9th Review Conference of the BTWC now scheduled for December 2022. We present here the results of a survey we carried out in early 2022 in order to assess the state of such resources.

2. Materials and methods

We carried out this survey project between December 2021 and April 2022, having weekly and then biweekly virtual meetings to decide and coordinate our activities. The project began with a literature survey for information about biosecurity education projects. We did not focus on the many research papers that have provoked such discussion about the problem of dual use or the major investigations of the governance of dual use in our survey, but we took a very broad view of biosecurity awareness-raising and education projects so as to include both attempts at testing methods and producing resource collections as well as efforts to practically raise awareness and to teach educational material. We investigated material from the literature survey and identified 39 people globally who had been involved in biological security education projects. We supplemented that list to some extent as we found new information during the project. All these participants are people who advocate biological security education globally, and who promote this very important issue to States Parties.

In the second stage of the project, we attempted to design an online questionnaire that would have both closed questions (i.e., multiple choice) that we used to obtain quantitative data and open questions

that allowed recipients to answer in their own words and thus give us more detailed qualitative data. Our preliminary questionnaire was then tested as a pilot with a small number of colleagues and the feedback was used to produce the final questionnaire. All of this work was completed by the end of January 2022 and the questionnaire was circulated to potential contacts through February and March 2022.

Our view from the information that was gathered in the literature review was that the projects that had been carried out since the turn of the century (when the problem of dual use became prominent) numbered at most about 100. Our aim was to obtain as near to 25 replies to our questionnaire as possible in the time and with the resources that we had available, so we sent several reminders to potential responders. In a small number of instances, we also asked responders for further information or clarification. A small grant from London Metropolitan University funded this work and the initial analysis of the questionnaires. We knew that we could not obtain important information on some biosecurity education projects, for example, the major activities carried out in Ukraine, and we also failed to get information on some projects that we knew had taken place. Given that many of the projects were of short duration and carried out over a 20-year period, these difficulties were anticipated. However, we thought that if we could get 25 replies, we would have grounds for at least making some tentative conclusions as to what had been attempted and achieved despite not having a proper random sample from all of the projects that had been undertaken. In the end, we received 26 responses to the questionnaire, but as might be expected, not all responders answered all questions.

Great care was taken to include a three-paragraph introduction to the online questionnaire that explained exactly what the information would be used for and how it would be used. In particular, it was stressed that the data submitted would be anonymous, kept securely for the period of the project, and destroyed 6 months after being submitted.

The closed (multiple choice) questions were: (1) Main people involved, (2) Name of the Organisation. (3) Name of the project, (4i) Name of the funding organisation, (4ii) Scale of funding received, (4iii) How easy was it to obtain the funding, (4iv) Source of funding, (5) Country in which the project was done, (6) Duration of the project, (7) Background of the project team, (8) Was dual use the main focus of the project, (9) What was the purpose of the project, (10) Was the project conducted for educational purposes, (11) Main targets of the project, (12) Ways to teach Biosecurity, (13) Method of teaching involved. The open questions that asked for more details in the responders' own words were: (14) Object of the project, (15) Content (outline) of the material used, (16) Method of the project, (17) Method of evaluation (if attempted), (18) What was the intended impact of the project, (19) Means used to sustain the use of the knowledge developed in the project, (20) Publications on the project, (21) Other information (if any). The questionnaire was distributed using Google Forms due to its efficiency, low cost and flexibility for customizing.

3. Results

3.1. The closed questions

The first three closed questions were only for administrative purposes in the event we had to check back with the responder. Therefore, the first question of relevance here is Question 4 on funding for the projects. As can be seen from Table 1A. the size of the funding ranged across our scale with both small and several quite large grants being obtained.

The data on the source of the funding for the projects is set out in Table 1B. It is notable that there were very few of the charity and private funders that would often be prominent in funding projects related to arms control and disarmament. The reliance on funding directly from government sources is clear and that point is reinforced by the breakdown of other sources where universities and other government funded institutions supported other projects.

The answers to our question on how easy it was to obtain the grant ranged from very easy to very difficult, but with no obvious relationship between the level of difficulty and the size of the award. However, as getting grants is rarely straightforward, it was a surprise to find the distribution of the answers to Question 4iii on the difficulty of obtaining the grants, where given, being very easy (2), slightly easy (2), neutral (6), slightly difficult (4) and very difficult (1). This suggested that the sponsors of the funds were perhaps seeking to fund such projects. The projects were organised in 15 different countries: Armenia, China, Croatia, Denmark, Germany, Italy, Japan, Kazakhstan, the Netherlands, Pakistan, Portugal, Tajikistan, Ukraine, the United Kingdom, and the United States. However, several of the projects involved reaching out to engage people in a number of other different countries. Thus, in combination, there was a reasonable coverage of participants in different States around the world. In regard to the duration of the projects, one project was completed in less than 6 months, nine projects took between 6 and 12 months, three projects took between 12 and 24 months and twelve projects needed more than 24 months to complete.

Table 1A
The scale of funding.

Amount	Frequency
Below $5,000	2
$5,000 - $10,000	6
$10,001 - $ 15,000	1
$15,001 - $20,000	2
Above $20,000	7
No funding (2) / Not stated (6)	8

Table 1B
The source of the funding.

Source	Frequency
Private / Charity	2
Government	15
Universities	4
Government funded institutions	2
Other	3

Table 2
The background of the project teams.

Background	Frequency
Academia	22
Life sciences	18
Other sciences	3
Social sciences	10
Humanities	4
Other (e.g., security law, etc)	5

Table 3
The purpose of the projects.

Purpose	Frequency
Raising awareness of dual use	21
Teaching dual use in education	15
Researching / Debating dual-use issues	11
Other (e.g., developing lectures, explaining legislation, evaluating methods)	12

Table 4
The main targets for the projects.

Main targets	Frequency
Life scientists	20
Researchers	17
Undergraduates	17
Postgraduates	15
The general community	6
Other (e.g., medical doctors, students in other disciplines)	8

Table 2 sets out the data on the background of the project team showing the number of times specific types of background were mentioned in the 26 returned questionnaires.

It is obvious that the main participants in the project teams were academics and life scientists. Few participants had a background in the Humanities which we see as essential given the emphasis in the Tianjin Guidelines on the importance of ethics. What is particularly clear is the lack of participation by members of the large and growing commercial biotechnology industry.

The next set of questions was aimed at finding out more about the content of the projects. Question 8 asked if dual use (the fact that "knowledge and technologies used for beneficial purposes can also be misused for harmful purposes" [19]) was the main focus of the project, or if that issue was considered in a wider context of biosecurity. In 15 of the projects, dual use was stated to be the main focus and in 11 a wider approach was taken. Question 10 asked if the project was carried out for educational purposes and 22 of the projects were stated to be for that purpose while 4 indicated that education was only a part of the purpose of the wider project. Question 9 attempted to investigate if the main focus of the project was on simply raising awareness or actually teaching about the subject, or if the project was directed to researching/debating, or, indeed, if it was focused on other issues. The results indicating how many times these topics were mentioned in response to the question on the purpose of the project are shown in Table 3.

Therefore, raising awareness was the most consistent objective, but teaching was also prominent in the projects as was researching and debating about dual-use and biosecurity. Question 11 then asked who were the main targets for such awareness-raising, education, and debating? Table 4 shows the number of times target audiences with different backgrounds were mentioned in the 24 responses.

It is obvious from this data that the main targets for the projects was the life science community from undergraduates and postgraduates through to professional research scientists.

The final two closed questions investigated teaching in more detail with the first (Question 12) asking if the teaching was as a whole course, part of a course, supplement to a course, in a different setting, or in different settings such as individual lectures. Fifteen responses indicated that a course, part of a course or a supplement to a course had been involved in the project, and five projects indicated that two or three of these options had been carried out. In total, nine projects included the teaching of a whole course, eight as part of a course, and four as a supplement to a course. Therefore, there have been a good number of courses and parts of a course developed and taught in these projects. The responses to Question 13 on the methods of teaching indicated that the methods used were very diverse as shown in Table 5 by the frequency of different methods mentioned in the 24 responses (Obviously with more than one method often being used in the same project).

The frequent use of methods other than straight lectures – such as online interactive and active learning methods - is clear from the data.

Table 5
Methods of teaching.

Methods of teaching	Frequency
Developing a resource	12
Delivering lectures	11
Active learning processes	10
Seminar and presentations	16
Online interactive course	4
Other (e.g., on the job training)	2

3.2. The open questions

The open questions were designed to provide finer-grain qualitative detail to add to the quantitative data provided by the closed questions. So, Question 14 asked for more information on the purpose of the projects. Examples of edited responses from Question 14 set out in the categories used in Question 9 are as follows:

A. Raising awareness

"To introduce dual-use awareness-raising elements into formal education in science and engineering…"
"Raise awareness of the risks for students, researchers and scientists…"
"…Raise awareness on biosecurity, including…legislation, dual-use dilemmas, ethics in research…"

B. Teaching

"…through education [it] is possible to achieve sustainable results…core idea is responsible science"
"… To develop an understanding of the Biological and Chemical Weapons Conventions and dual use issues, and to foster a sense of ethics as a researcher."
"To develop a [teaching] resource that could be widely used by others."

C. Researching / Debating

"Discussions about the concerns of misuse of knowledge leading to development of bioweapons and supporting effective systems of governance for life sciences research that may raise dual use issues."
"Investigate potential vulnerabilities in high-value life science facilities and operations."
"To raise awareness of dual use issues by a novel method but became an investigation of the lack of knowledge of dual use."

D. Other

"To promote a culture of responsibility and guard against misuse, all scientists…are encouraged to incorporate elements from the Codes of Conduct for Scientists into their … practices, protocols, and regulations."
"Strengthening the global culture of biosafety, biosecurity and responsible conduct in the life sciences."

Table 6
Number of mentions of ways and methods.

Ways and methods	Number of times (frequency)
Developing a resource	9
Delivery lectures	9
Seminars/ Discussions	6
Implementing a course	5
Presentations	4
Active learning (TBL) exercises	3
On-the-job training	2
Focus groups	2
Mentoring	1
Comparing methods	1
Expert videos	1
System analysis	1

"Evaluation of TBL [Team-Based Learning] Active Learning."

It seems evident that, while the projects arose from a wide variety of different motivations and within different contexts, running through most was a central concern about the problem of dual use and the idea of responsible conduct of research as a core part of the solution [20].

In view of possible concerns about intellectual property rights, we carefully asked only for an outline of the topics covered in the response to Question 15 "Content (outline of the material used)". We also supplied a list of examples of the topics that we thought might be mentioned stating "e.g., history of biological warfare, history of the 1925 Geneva Protocol, development of the 1970s BTWC, development of the 1990s CWC, the problem of dual use, various experiments that have caused concern, the current state of the BTWC and ongoing negotiations, and so on." Eight of the project returns indicated that they essentially covered this range of topics, but 12 projects indicated that their focus was on, or included, other specific issues such as "weapons and underlying technologies", "regulations and legislation", "Nuremberg Code and the Declaration of Helsinki", "building an effective web of prevention" and "discussing and sustaining robust oversight systems." Six responses stated that specific curricula had been designed for the project without going into any detail.

Question 16 on what the method(s) was used in the project was intended to fill out the data in Questions 12 and 13 of the closed questions on ways (e.g., a whole course) to teach and methods (e.g., lectures) of teaching. As several different ways and methods were mentioned in some responses, we counted the frequency of the mentions of a way or method in all of the responses. Table 6 therefore shows the number of times the various ways and methods were mentioned in the responses.

Clearly the projects explored a wide variety of different ways and methods.

We received 23 responses to Question 17 on the method used for evaluation of the project. These responses seemed to us to fall into a small number of general categories as set out in Table 7.

It will be noted that for the main part these evaluations referred to the immediate near-term impact of the project and not to longer-term changes in behaviours.

The answers to Question 18 on the intended outcome of the projects were almost all short, sharp and emphasised awareness raising (5 answers), responsible conduct of research / preventing misuse (7 answers) and improving and sustaining effective teaching (6 answers). Examples in each category are:

A. Awareness-raising

"To broaden awareness of biosecurity issues in general, but also to provide a solid grounding in biosecurity for those working or studying in related fields."

"Maintain a high level of awareness as a scientist, take pride in being a researcher, and develop a high level of insight into the dual-use issue."

B. Responsible conduct of science / Preventing misuse

Table 7
Method of evaluation (if attempted).

Methods of evaluation	Number of times (frequency)
Discussions with participants	3
Questionnaire responses by participants	4
Evaluation by organisers	5
Feedback from other assessors	8
Tests of participants (exams, essays, online)	3

"Integrating discussions of dual-use governance into a unified educational process that addresses responsibilities of scientists and encourages thinking."

"…to prevent misuse of bioscience research without hindering beneficial outcomes in accordance with the articles and norms of the Biological and Toxin Weapons Convention, and in advancement of progress towards achieving the UN Sustainable Development Goals."

C. Improving and developing teaching

"…to put together a single one-stop-shop educational module resource on biosecurity and make it available on the web in a variety of languages."

"Local ownership of the master's course and sustainability."

The problem of sustainability was the subject of Question 19. A small number of projects concerned courses that had been run annually over a number of years. Despite their diversity, sustainability was obviously an issue of importance for almost all of the other project organisers. We divided the different approaches mentioned in the responses into four broad categories: ensuring the continuation of the project (2 answers), spreading information about the project (3 answers), developing the project further (4 answers) and widening the use of the project results (7 answers). Examples are:

A. Ensuring continuation of the project

"…we have created some…options for participants for ensuring stability of the project. For example, discussions in the Ministry of Education…"

B. Spreading information about the project

"Publications, lectures and invited presentations, many views/citations of published articles and chapters…"

C. Developing the project further

"We started out as an annual experiment, but over the years we have incorporated it as a permanent undergraduate and postgraduate slot."

D. Widening use of the project

"Follow-on support, assistance with national and regional network building, development of shared research networks.

The information given in response to our last two questions on publications from the project and any other information was mainly to help us follow-up further details of the projects.

4. Discussion and conclusions

We are not aware of any full compilation of all of the biosecurity education projects that have been carried out over the last two decades, and we are certain that we have not managed to obtain responses from some projects that have been carried out such as those in Ukraine [11] and in the Middle East and North Africa [21] and in West Africa [22]. Therefore, our aim was not to carry out a systematic random survey of all of the projects that have been carried out and to provide a detailed account of this research effort. However, given our limited resources, that was never our aim. Our purpose was rather to try to answer the question "What range of resources and experiences have been developed in these biosecurity projects that might be helpful to States Parties interested in effectively implementing the *Tianjin Biosecurity Guidelines for Codes of Conduct for Scientists* after the 9th Review Conference of the BTWC in late 2022? As we explained in our introduction, given our estimate of the number of relevant projects we thought that if we could obtain about 25 responses to our questionnaire, we would have some hope of achieving that aim.

Many working in the life sciences might question why we think that education is so important to the effective implementation of the Tianjin Guidelines. As explained in the introduction, we agree with those who argue [23] that without awareness-raising and biosecurity education, life scientists are unlikely to appreciate the importance of building codes of conduct based on the guidelines and using the codes developed to engage the life science community in responsible research that helps to guard their work from misuse. The basic case for this point of view was set out clearly in the World Health Organisation's draft *Global Guidance Framework for the Responsible Use of Life Sciences* which was put out for public consultation in February 2022 [24]. In a sub-section titled "Persistent lack of awareness", the document stated that:

> "A chronic and fundamental challenge in biorisk management is that many practising scientists, technologists, and other managers and funders of scientific research and technology development are not aware that their work could be misused in ways that result in health and security risks to the public. The lack of awareness is unsurprising, given that biorisks are often overlooked or underemphasized in both educational curricula and on-the-job training."

The document continued:

> "Among stakeholders overall, there is a lack of awareness of biosecurity, biosafety and dual-use research. Globally, many scientists conducting life sciences research are not trained in biosecurity, not familiar with the BWC and not incentivized to devote time and resources to biorisk management…. Thus, high priorities for any biorisk management system must include education, awareness building, and creation of a culture of individual and institutional investment in biosafety, biosecurity and oversight of dual-use research."

And it did not underestimate the problem adding that:

> "The scale of the problem of the need for awareness raising and education should be understood. Globally, life scientists' number in the millions and this number is likely to increase in the future. Only a small percentage of life scientists are aware of, and have the ability to manage biosafety, biosecurity and dual-use issues. Improving biorisks management will require resources. Collaborative ambition among stakeholders along with changes in awareness raising, education, training, professional development and cultural shifts will be critical to help meeting the challenge."

These then are the reasons why we wanted to make a contribution to understanding what resources and experiences have been developed for biosecurity education for life and associated scientists. The one weakness on our survey lies in the small number of contacts and responders for reaching general conclusions. However, at the same time, this small number, no doubt reflecting the small number of groups seriously addressing the education issue, actually makes one of the strongest arguments for the need for concerted, timely, directed action.

Therefore, at the present time there will be few life scientists with the Ethical Competence which Kuhlau [25] and her colleagues described in 2012 as involving:

> "… three core capabilities: 1) *awareness*, to initially recognise an ethically challenging situation; 2) *reflection*, to ethically reflect on it; and 3) *action*, to adapt one's behaviour to it. (Original emphases)

Ideally then, those taking up the task of improving the awareness and education of life scientists to assist in the professionalisation of the community [26] would have a range of awareness-raising courses suitable for undergraduates, postgraduates and life science researchers in which the *contents* had been carefully evaluated and replicated in practical projects. Similarly, they would have at their disposal a range of education *methods* that had also been designed for a range of different potential participants and carefully evaluated and replicated in practical projects. Moreover, the materials used in such projects would be available in multiple languages and there would be national, regional and international collaborative groups, that were involved in the development and testing of these diverse strategies, available for them to join. Our biosecurity education survey was intended to discover how near we are to that ideal situation after the last two decades of growing concern about dual use research in particular and biosecurity more generally.

If we assume that for the Social Sciences small grants are generally below $5,000 and medium-sized grants are between $5,000 and $20,000 then it is important to note from the responses to Questions 4 (i-iv) that while most funding for work in this area has been in small to medium sized grants (or unfunded *via* grants), there have been some large and repeated grants for work on biosecurity awareness-raising and education. Moreover, almost all of this funding has come from Government sources directly, or indirectly. Thus, there would seem to be an opening for non-Government funders to increase their funding given the increasing public concerns about biosecurity especially after the COVID-19 pandemic and the ability of such funders to take more risks with supporting the kinds of innovative experimental approaches [27] that will be needed to deal with the size of the biosecurity educational problem in life science community.

However, while it was not the subject of this survey, it should also be noted that there is a large and growing literature that can be called on as a resource in biosecurity awareness-raising and educational activities. This literature includes multi-authored books on the history of offensive programmes [28] and the impact of advances in science and technology on the non-proliferation regime embodied in the Biological and Toxin Weapons Convention and the Chemical Weapons Convention [29]. There are additionally hundreds of academic papers have been published on aspects of the dual-use problem and the culture of biosafety, biosecurity and responsible conduct in the life sciences (see reference 12) and much of the official proceedings of the meetings of States Parties to these Conventions is readily available on the internet.

The wide variety of education tools clearly identified in this survey will be very useful in planning curricula, as the different tools allow different types of approaches that would be most appropriate for a particular case or area of studies, or even in different countries with different culture backgrounds. We would think these considerations of best or good practices could best be worked out through network approaches (as discussed below). In addition, other key practical questions such as whether biosecurity education should be mandatory as opposed to elective, whether it is important to reach most or all of life and associated scientists, and whether people in other interdisciplinary research and other stakeholders should also be included, while not discussed in this study, will have to be addressed during the implementation of effective codes of conduct.

Against that background how close are we to the ideal situation which we would like to be in, should the States Parties to the BTWC decide to adopt and begin to implement the Tianjin Guidelines? Our survey indicates (see Table 2) that most of the organisers of the biosecurity awareness-raising and educational activities undertaken to date were academic life scientists. Therefore, there is probably a good cohort of life scientists with knowledge of how to set up these activities that can be called upon to assist in new ventures. Moreover, as the projects were carried out in a wide range of different countries, this expertise should also be widely spread in different countries around the world. However, it should be noted that the original language used in these projects was usually English and very few involved making translations of the material used even into the six official UN languages. This is a problem that will have to be addressed if the kind of progresses needed is to be achieved. Unfortunately, the responses to our survey also indicate that there have not been many people in the Humanities (that is with specific expertise in ethics) involved and

given the emphasis on ethics in the Tianjin Guidelines, this is a gap in capabilities that will probably have to be seriously and quickly addressed. The projects surveyed were focused (see Table 3) mainly on awareness-raising and teaching, with some also including researching and debating dual-use issues to better understand the problem. So again, there should be a good cohort of people who have experience of the practicalities of carrying out these projects.

The main participants in the projects (see Table 4) were life scientists and these were across the range from undergraduate, postgraduate through to people doing research. Some other people with scientific background (for example medical doctors) were involved in some projects as participants, but few projects involved people such as those working in information technology or engineering. This is obviously a gap that should be addressed quickly as dual-use concerns certainly also arise in such sciences and technologies associated closely with the life sciences. The methods of teaching in addition to developing resources (see Table 5) were diverse with delivering lectures using active learning processes, seminars and presentations being well represented. Other methods such as interactive online courses and on-the-job training were less evident. It seems to us that to meet the scale of the awareness-raising and education requirements in biosecurity for life and associated scientists, much more effort will have to be put into finding ways of engaging larger numbers of people such as through developing innovative methods including manga, cartoons, animations and films and making them freely available on the internet [17]. Interestingly, when given the chance to expand on what was done in the projects in Question 16 responds made clear that there was a greater diversity of approaches. As can be seen in Table 6, focus groups, videos of experts, mentoring and so on were also used in some of the projects. We were very careful just to ask for an outline of the contents of the material used in the projects, and simply gave a list of what might be included along the lines we would have used [30,31]– that is centred on the two Conventions and the problem of dual use within that context (see the explanation of Question 15 above). Seven of the responses indicated that the material used was along these lines, but others usefully indicted that they either added more material to this list or had a rather different focus. Clearly lacking at the present time is an easily available up-to-date teaching resource covering the key issues involved in biosecurity awareness-raising and education – and available in at least the six official UN languages.

Open Question 14 asked for more information on the purpose of the projects to add to the quantitative data in Question 9. As noted above, (in Table 3), the main themes were awareness-raising, teaching, researching, and debating. The information in the open question added details to these main themes and emphasised the very low number of projects devoted to specifically evaluating the utility of different methods of raising awareness and teaching biosecurity. We tried to explore the issue of evaluation with open Question17 and grouped the responses into the general categories and frequencies shown in Table 7. It seems to us that most of these methods of evaluation are not very sophisticated, and we agree with those who have suggested that within the field of biosecurity awareness-raising, education, and cultural development, there should be a greater effort to learn from the more sophisticated methods used in related fields [13]. We could not either find within our survey any project devoted to attempting to replicate an earlier project. This may, of course, be related to the difficulty of obtaining funding for such replication studies. In Question 18, we checked again on the intended impact of the projects and the responses mapped closely back to the purposes set out previously (see Table 3 and the answers to question 14).

Finally, in Question 19 we enquired about the means used to try to sustain the use of the knowledge gained in the projects. We thought that the answers which could be grouped into four broad categories of ensuring that the project was continued, spreading information about the project, developing the project further, and widening the use of the project. This latter point raises the question of how local, national, regional and international networks may be important in the future implementation of the Tianjin Biosecurity Guidelines and the continued development of the incorporation of dealing with dual use issues and biosecurity in general within the concept of responsible conduct of research. In this regard, we would note the extensive listing of biosecurity education and awareness-raising projects in Box 5 on "Illustrative examples of awareness raising, education, training and capacity building in the life sciences and related fields" in the World Health Organisation's final summary document of May 2022 titled *Towards a global guidance framework for the responsible use of life sciences: summary report of consultations on the principles, gaps and challenges of biorisk management* [3]. This and other information on relevant networks plus the growing use of self-assessment systems [32] to enable the engagement of in dividual scientists can be seen as additional mechanisms for gearing up the development of biosecurity awareness-raising and education. In the longer term we believe that a dedicated international network similar to the International Nuclear Security Education Network (INSEN) run through the International Atomic Energy Agency (IAEA) will be required to properly support the cultural change needed in the life and associated sciences.

In conclusion, we suggest that our survey shows that while all of the ideal elements required to effectively implement the Tianjin Guidelines are obviously not yet in place, the efforts of multiple groups over the last two decades has put in place resources and experience that can be fruitfully used in that endeavour over coming years, and that the deficiencies identified here can also be remedied relatively quickly if efficiently addressed.

Acknowledgements

We would like to thank all people who assisted us in publicising our survey and particularly those people who took the time and trouble to fill out the 21 questions so diligently. We would also like to thank Dr Maria Espona and Professor Kathryn Nixdorff for their detailed comments on a draft of this paper. The survey project was funded by a London Metropolitan University internal funds.

Conflict of interest statement

The authors declare that there are no conflicts of interest.

Author contributions

Lijun Shang: Conceptualization, Methodology, Formal Analysis, Writing – Review & Editing, Supervision, Project Administration, Funding Acquisition. **Michael Mprah:** Investigation, Formal Analysis, Data Curation. **Indrajitrakuraj Ravi:** Investigation, Formal Analysis, Data Curation. **Malcolm Dando:** Conceptualization, Methodology, Formal Analysis, Writing – Original Draft, Writing – Review & Editing, Supervision.

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