

1 **Fueling the Bio-economy: European Culture Collections and Microbiology**  
2 **Education and Training**

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23 **Abstract**

24 **A survey of European Microbial Biological Resource Centers and their users**  
25 **provided an overview on microbiology education and training. The results**  
26 **identified future increases in demand despite several shortcomings and gaps in**  
27 **the current offer. Urgent adjustments are needed to match users' needs,**  
28 **integrate innovative programs, and adopt new technologies.**

29

30 **Microbial Diversity and Microbiological Resource Centers**

31 The abundance and diversity of microbes is breathtaking, as emphasized in multiple  
32 studies. For example, current estimates of the total number of bacterial cells on Earth  
33 ( $4\text{-}6 \times 10^{30}$ ) outnumber the estimated number of stars in the universe by several orders  
34 of magnitude ( $10^{21}$ ) [1]. Microbes are incredibly resilient and successful, populating  
35 all sorts of different environments, including several inhospitable ones previously  
36 thought to be sterile (e.g. healthy placentas [2], black smoker fluids in hydrothermal  
37 vents [3], deep-sea brines [4]). They dominate not just our oceans, terrestrial sites, and  
38 deep subsurface environments, but also our own bodies: total counts show that  
39 bacteria associated with the human body thrive and outnumber our own cells and  
40 genes at 10:1 and 100:1 ratios, respectively [5-6].

41

42 Due to their enormous genetic and functional flexibility, microbes have a wide impact  
43 on our planet. Microbes, either being beneficial or detrimental, play essential  
44 ecological roles, interacting with plants and animals, and control vital global  
45 geochemical and nutrient cycles. Humans have been making direct use of microbes  
46 since the dawn of humankind - originally associated with the production of fermented  
47 foods and beverages - but during the past half century as producers of antimicrobial

48 agents and enzymes for application in various areas of modern-day biotechnology  
49 (e.g. for medicines, fuel production, farming and food industry, forensics, and  
50 bioremediation [<http://www.oecd.org/science/biotech/1890904.pdf>]).

51

52 Public microbial culture collections and the quality-managed Microbial Biological  
53 Resource Centers (mBRCs) fuel the Bio-Economy: they preserve biodiversity, and  
54 provide access to authenticated microbial resources and to associated data and  
55 expertise. Future innovation in biotechnology heavily depends on the use of microbial  
56 resources as raw materials, as well as on access to knowledge and expertise in the  
57 various disciplines within microbiology.

58

59 MIRRI (the Microbial Resource Research Infrastructure: [www.mirri.org](http://www.mirri.org)) is a  
60 European Union project as part of the ESFRI initiative by the European Council  
61 (European Strategy Forum on Research Infrastructures: <http://www.esfri.eu/>). MIRRI  
62 involves 16 partners in 11 European countries and 27 Collaborating Parties in 8 other  
63 countries, collectively holding over 1 million microbial strains, plasmids, viruses, and  
64 DNA samples. This project, which is currently at the end of its preparatory phase,  
65 aims to solve the long-standing issues of fragmentation and overlap in holdings,  
66 services, and education and training (E&T) offered by mBRCs. In general, it will  
67 allow coordination between the different mBRCs and create a pan-European  
68 distributed research infrastructure that will ensure a harmonized broadening of  
69 holdings and connect resource holders with end-users more efficiently, thus,  
70 promoting knowledge transfer and fostering innovation [7-9].

71

72 One crucial element towards achieving these goals is to properly define the user  
73 community, and identify trends in the current and future demand for services, as well  
74 as possible gaps and bottlenecks. A survey was performed to identify these and is  
75 discussed below together with specific recommendations.

76

### 77 **Education and Training Requirements in Microbiology**

78 A questionnaire-based survey was established, targeting current and potential users of  
79 microbial resources and services and aiming to identify trends in demand for all  
80 services provided by mBRCs, as well as possible gaps [10]. From a total of 1146  
81 individual users, 998 replies (758 from non-profit sector, and 238 from the for-profit  
82 sector) were collected and analysed on the basis of E&T.

83

84 Despite the widely recognized importance of E&T in technology transfer and  
85 innovation, only a low number of respondents accessed E&T from any external  
86 sources. Merely 17.9% of respondents outsourced E&T in the past five years, while  
87 even less (15.9%) intend to do so in the next five years. The differences between the  
88 for-profit and non-profit sectors were minor; although for the latter, demand for the  
89 next five years is expected to remain stable. The scenario for E&T outsourced to  
90 mBRCs looks somewhat positive as increases in demand are expected for the next  
91 five years, particularly in the for-profit sector with a 5.8% growth.

92

93 Multiple factors were behind the low use of the E&T offered in microbiology by  
94 mBRCs (**Figure 1**). While some stated that E&T are not needed and/or are taken care  
95 of in-house, others pointed to the lack of visibility of mBRC teaching and training and  
96 other shortcomings (particularly on price-competitiveness). Despite the presence of a

97 wide E&T offer to users, they were listed as the second highest service that repliers  
98 were “not aware of” as being provided by mBRCs, a trend particularly pronounced in  
99 the for-profit sector.

100

101 We also observed that the list of E&T topics identified in replies by mBRC users is  
102 markedly different when comparing the for-profit and the non-profit sectors.  
103 Remarkably, the highest rated topics by respondents from the for-profit sector are  
104 much more aligned with the classic core-activities of mBRCs (e.g. microbial  
105 identification and characterization, microbial cultivation, and preservation).  
106 Respondents from the non-profit sector (predominantly in academia) are likely better  
107 suited to address such issues in-house, having higher demand for topics associated  
108 with higher-end technologies and tools (e.g. data analysis, molecular tools). Such  
109 differences reflect the specificity and differentiation in needs and skills required and  
110 available in academia and industry (**Figure 1**).

111

### 112 **Current Offer in E&T in Microbiology provided by MIRRI mBRCs**

113 An additional survey targeting mBRCs within the MIRRI consortium was designed  
114 and circulated. Replies from 28 mBRCs across Europe (almost all of the MIRRI  
115 mBRCs) provided a snapshot of current education and training, tools, and contents  
116 being used and produced within the consortium, identifying areas that need  
117 improvement. The scenario revealed by this second survey needs special attention.

118

119 E&T still relies almost exclusively on face-to-face interaction (only one partner  
120 makes use of combined face-to-face and online interaction, i.e. b-learning or blended  
121 learning). Likewise, and despite the current trends in increased use of new formats for

122 E&T, current offerings by MIRRI mBRCs still are overwhelming dominated by a  
123 traditional lecture-centered style with support of textbooks or print materials (only 1/3  
124 of MIRRI mBRCs make use of video, interactive, or other types of new learning  
125 resources, and only about 1/4 of MIRRI mBRCs produce them).

126

127 It is also interesting to note that some mBRCs within MIRRI do not offer E&T as part  
128 of their services. This is usually due to lack of personnel and/or financial resources.  
129 However, most collections recognize the need to expand E&T as part of an improved  
130 offer to users. The set of innovative tools available will permit the integration,  
131 modernization, and harmonization of the MIRRI E&T offerings and fill the identified  
132 gaps, by developing and designing new approaches to deliver E&T and supporting the  
133 improvement of the current offerings. Specifically, it is recommended to: (i) bridge  
134 the current gap between E&T offerings and demand by implementing new courses  
135 either in continuing professional development (CPD) schemes or post-graduate  
136 (masters and PhD) degrees offered with higher education institutions; (ii) increase  
137 awareness of E&T offerings by advertising on home websites and on course  
138 aggregators; and by running massive open online courses (MOOCs) on a selection of  
139 general topics; (iii) increase course attendance by widening offerings to prospective  
140 trainees in remote locations via online accessible contents using small private online  
141 courses; (iv) improve E&T quality by constant content update and review; (v)  
142 contribute to development of a portfolio-based professional culture that will permit  
143 the development of unique profiles of skills and capacities in jobs for the future,  
144 through the flexibility, comprehensiveness, and accreditation of E&T offerings (as  
145 discussed by multiple research infrastructures, namely within e.g. the LifeTrain and

146 EMTRAIN projects; [15]); (vi) create trust on the MIRRI label and shift towards  
147 bioindustry needs.

148

149 mBRCs role in underpinning future biotechnology breakthroughs should also rely on  
150 knowledge transfer on topics such as new cultivations methods for less common  
151 microbial groups, or microbial identification with integration of new cutting-edge  
152 technologies (e.g. next-generation, single-cell, and whole genome sequencing as well  
153 as MALDI-TOF MS). These key E&T topics have not been fully explored and can  
154 accelerate the development of new bioproducts and services. Such a role for mBRCs  
155 reflects the central position of research infrastructures in innovation in new  
156 technologies, and a privileged role in training researchers in how to make the most of  
157 such new advances and technologies.

158

### 159 **Concluding Remarks**

160 mBRCs are key holders of microbiological resources, data, and expertise which are  
161 crucial for research and innovation. Furthermore, E&T are one of the main paths for  
162 knowledge transfer between mBRCs and users of microbiological resources in  
163 academia and, most importantly, in industry. Nonetheless, this service has received  
164 insufficient attention, has been hampered by access to limited resources, and  
165 information on present and future needs and demands has never been previously  
166 collected.

167

168 There is a much wider market available in the field of E&T, and the demand is likely  
169 to increase in the future. mBRCs still rely on outdated methods and tools for E&T,  
170 and are clearly underprepared to face this challenge. Further efforts are clearly

171 required in adjusting E&T offer, adapting contents and content delivery whilst  
172 focusing on cost-efficiency and efficient advertising to increase visibility. MIRRI's  
173 ongoing efforts in this field will facilitate: (i) the pooling of resources, and (ii) the  
174 coordination of training content production, courses offered, and their advertisement.  
175 Adopting e-learning, b-learning, video, and interactive content will be particularly  
176 beneficial due to scalability, and the production of reusable and 'mashable' content.  
177 Also, this will increase the reach and accessibility of E&T courses, reduce  
178 unnecessary face-to-face components, optimize course duration, and reduce costs to  
179 mBRCs and end-users. Such improvements will contribute significantly to the  
180 sustainability of mBRCs.

181

182 Improving the current E&T offered by mBRCs is a complex task, but an essential one  
183 if we want to increase its quality and effectiveness, better align them with the needs of  
184 end-users, and thus assist in fueling the current and future waves of innovations in  
185 biotechnology.

186

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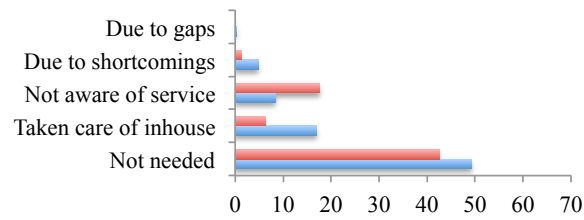
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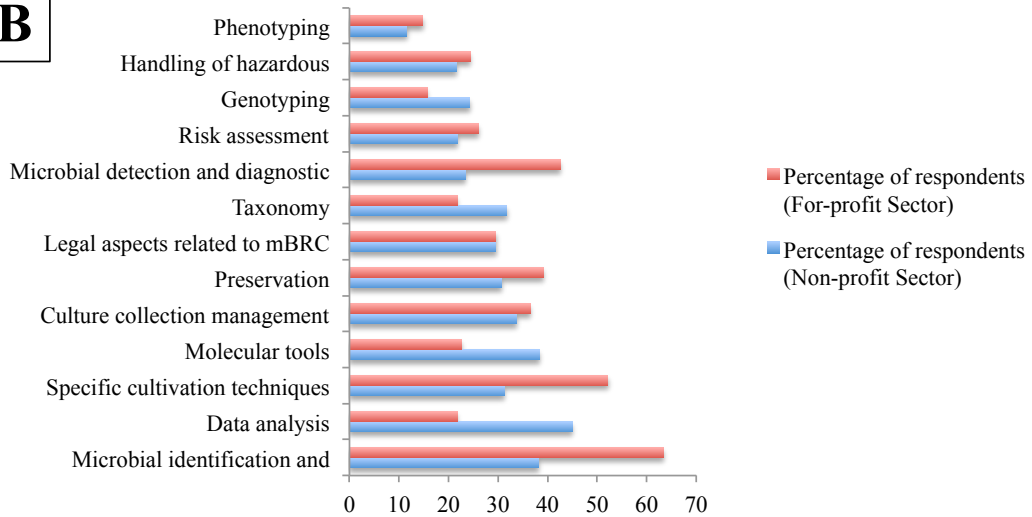
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**A**



**B**



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248 **Figure 1.** Overview of Reasons Invoked For Not Making Use of Microbiological  
249 Training Provided by mBRCs (A) and Top Training Topic Needs Identified by For-  
250 profit and Non-profit Sectors (B).