



A Road to Microbiology Literacy (and More): an Opportunity for a Paradigm Change in Teaching

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Microbial activities pervasively impact the wellbeing of all organisms, including humans, and the functioning of the planet itself. In order for society to form informed opinions and take effective actions related to its welfare, it must be able to understand the causes of issues of importance and to appreciate the range of possible responses and their likely effectiveness. Society must become microbiology literate. The International Microbiology Literacy Initiative is creating a comprehensive range of teaching resources that will constitute a child-centric school curriculum of societally relevant microbiology. The core of the teaching resources, the lessons, are somewhat unusual in that each one is designed to be essentially stand-alone, so courses can be individually structured by teachers according to their perception of what is interesting and important for their charges. Moreover, the lessons deal not only with societally pertinent microbial activities, but also discuss and propose discussion of their relevance to sustainable development, of their impact on policies and decisions (personal, community, and national), and of issues of stewardship and stakeholder responsibilities. The class lessons are complemented by other child-centric teaching resources whose functions are to add value, to stimulate pupil imagination and excitement in discovery, to engage pupil interest and enthusiasm for topics like sustainability, climate change, international cooperation, citizen science, etc., and to empower pupils as stakeholders in their microbiology education and as educators and multipliers.

KEYWORDS microbiology literacy, generational contract, global warming, interconnectivity, microbiology curriculum, polycrises, societally relevant microbiology, stakeholder, stewardship, sustainability

EDITORIAL

Why is microbiology literacy in society essential? Microbes and their activities touch us personally in so many different ways, play vital roles in our wellbeing, and constitute the life support systems of essentially all organisms and indeed of the planetary surface. They lie at the center of the bioeconomy, especially of the discovery and development of new medicines and vaccines, of agricultural yields and food security, of sanitation and the provision clean water, of the health of the environment, biodiversity, and sustainability. Crucially, they are key players in the polycrises currently challenging humanity.

Without understanding the roles of microbes in important processes that affect us directly and indirectly, we are

unable to comprehend what is going on and why, what are the causes of and, crucially, potential solutions to needs and problems, and thus to form informed opinions and take objective constructive decisions and effective actions. The scale and pervasiveness of microbial influences on decision-relevant processes in many spheres at all levels is huge.

In order to promote the beneficial properties of microbes and counteract their negative activities at the personal, family, community, national, and global levels, people need to become literate in societally relevant aspects of microbiology. The generational contract compels us to ensure that the next generation, which will inherit all current problems not solved by us and all the new ones we are creating, is fitter than we were to solve the problems they face. As previously stated, “Microbiology literacy needs to become part of the world citizen job description” (1).

Achievement of microbiology literacy in society requires the incorporation of appropriate topics of microbiology into school curricula (1). But, to enable this, there needs to be a comprehensive range of teaching resources that constitute a societally relevant microbiology curriculum. To my knowledge, this does not exist.

The publication of the case for microbiology literacy (1) signaled the launch of the International Microbiology Literacy Initiative (IMiLI), which aims to create the teaching resources

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TABLE I
The topic framework sections

1. Our Plants	12. New Frontiers
2. Our Animals	13. Microbial Gifts (Biotechnology)
3. Our Food	14. Their and Our Future
4. Ourselves	15. Their and Our Past
5. Our Health	16. Our Civilization and Culture
6. Our Infections	17. Our Microbial Friends
7. Our Planet	18. Microbial Wellbeing
8. Global Warming	19. How We Study Microbes
9. Our Water	20. Why We Need to be
10. Global Microbiology	Microbiology Literate
11. Adventures and Discovery	

that will form a school microbiology curriculum, and more, much more. The core of the resources are the lessons, 300+ topic frameworks (TFs), i.e., generic knowledge frameworks that describe in nonspecialist language the key elements of different topics from which teachers can select and adapt to whichever age group they are teaching and to their learning needs (Table 1). This core material will be complemented by TF-specific teaching aids, class experiments, class excursions (2), portrait galleries of famous and important microbes, and other teaching materials. All resources are being created *pro bono* by hundreds of committed microbiologists worldwide and are being made freely available.

Of course, there are the nay-sayers, informing that school curricula are rigid and that change is difficult. But the IMiLI is an international movement and the education systems of different countries vary in the flexibility of their curricula and their abilities and enthusiasm to incorporate new materials, so the speed of progress may vary considerably between nations. Appreciation of the need for adoption of a microbiology curriculum may well accelerate as a result of international benchmarking (for another discussion of international benchmarking in a different context, one concerning the 2019 coronavirus disease [COVID-19] pandemic, see reference 3): that is, countries benefitting from early introduction of microbiology into school curricula may exert a “pull” effect on others. But, in any case, change will not happen unless we push, and when we push, we will see how much resistance there really is. Importantly, there are discussions in a number of countries about how current school curricula may not be sufficiently fit for the purpose, not adequately preparing young people for the adult world of today and tomorrow, and what new topics need to be introduced to correct content deficits (e.g., <https://widgets.weforum.org/nve-2015/chapter1.html>). In this regard, it is important to note that microbiology is a branch of biology which is a curriculum topic in most countries, so in principle its introduction could simply involve some expansion and restructuring of existing curricula. In any case, necessity is the mother of invention, and change, like reproduction, is a characteristic of biological systems, including those organized and managed by humans.

The overarching goal of the IMiLI teaching resources is to provide children with knowledge and understanding of key societally relevant microbial activities, their impacts and consequences, and how they can be influenced for societal and planetary benefit. But these teaching resources also aim to widen the perspectives of children and adults.

We are all stewards and stakeholders. The world of the 21st century is very different from that of the 20th century: we are currently faced with polycrises (https://www.weforum.org/agenda/2023/01/global-risks-report-2023-experts-davos2023/?utm_source=sfmc&utm_medium=email&utm_campaign=2793318_AgendaWeekly13January2023&utm_term=&emailType=Agenda%20Weekly), including exceeding planetary boundaries and tipping points (4–7; <https://www.carbonbrief.org/explainer-nine-tipping-points-that-could-be-triggered-by-climate-change/>). These calamities have been created primarily by human overpopulation and the misguided belief that perpetual economic growth is both necessary and somehow sustainable, which are both rapidly exhausting planetary resources and promoting global warming by excessive production and release of greenhouse gases (8–10). The increasing deficits and asymmetries of availabilities of essential resources among and between peoples are a significant cause of regional conflicts, some of which can lead to global instability (11). Even for high-income countries, pandemics and wars can create major disruptions in supply chains of essential goods and services, disruptions that in the future should be minimized by adequate preparedness (12). The changes in human behavior needed to mitigate these crises are profound and require acceptance by society; such acceptance needs society to understand both the causes of the calamities and the potential mitigating options, including microbiological options, and their consequences.

Key to acceptance of the need for behavioral adaptation to the changed and changing world is wider recognition that we are all stewards with a duty of care—of ourselves, our families, communities, nations, the environment, and the planet. Daily personal decisions about food (e.g., meat and dairy with their carbon footprints), transportation (use of the car, with its carbon footprint, versus public transport, walking, or use of a bicycle or scooter), and a host of other issues collectively have important environmental consequences that affect the entire world. So, we need to ensure that they are informed decisions. While individually we may not be involved in making sustainability-relevant decisions at a national level, we are nevertheless key stakeholders having a vital responsibility to scrutinize decisions and hold decision-makers to account (13).

Society needs to comprehend and accept that everyone is a stakeholder and a planetary steward at some level and that both personal involvement and judiciously influencing decision makers is important. To facilitate and encourage the appreciation of the notions of stewardship and stakeholders, each TF has a component, the potential implications for decisions, with suggestions for class discussions around choices and decisions, at the personal, community, and national levels, and potential

consequences, and of stakeholder issues inherent in the topic of the TF.

Microbiology and sustainability. Much of the societally relevant microbiology discussed in the TFs is sustainability relevant. Issues relevant to the Sustainable Development Goals (<https://sdgs.un.org/2030agenda>) are summarized at the outset of the TF and explained in more detail toward the end. In explaining the sustainability relevance of microbial activities (see reference 14 and also <https://sfamjournals.onlinelibrary.wiley.com/toc/17517915/2017/10/5>), the TFs are not only raising awareness among teachers and pupils, but also are actively teaching about sustainability and the sustainable development goals.

The wider context, the interconnectedness of everything, countering silo mentality. One major problem inherent in current decision-making is the tendency to view a problem in isolation and develop a solution strategy without due consideration of all of the interconnected issues that influence the problem and that may react, often in unanticipated ways, to the proposed strategy. As remarked by John Muir: “When we try to pick out anything by itself, we find it hitched to everything else in the Universe (https://vault.sierraclub.org/john_muir_exhibit/writings/misquotes.aspx).”

The IMiL aims to counter issues being viewed in isolation by emphasizing the interconnectedness of things. Many of the TFs expose interconnectedness, with one TF dedicated to the issue of interconnectedness and two TF sections on Global Warming and Global Microbiology. Connectedness with the past and future are also revealed in the three sections, Their and Our Past, Their and Our Future, and Our Civilization and Culture. Moreover, in a further component at the end of TFs, Pupil Participation, there are questions and exercises designed to expose and stimulate consideration of the broader context of issues.

Because of an increasing appreciation of the need for change in order to equip the next generation of adults with knowledge and understanding more pertinent to the challenges and opportunities they will face (e.g., <https://widgets.weforum.org/nve-2015/chapter1.html>), school curricula in general and the way children are taught will come into the spotlight and be subjected to close scrutiny. This will create opportunities for some significant beneficial changes, three of which I would like to highlight here, summarized by the three Es: excitement, engagement, and empowerment, which are at the heart of a key principle, child centricity, of the IMiL school curriculum concept.

Excitement. Children are sponges for information, readily excited by discovery, and have wide-ranging imaginations. Microbiology research and development are exceptionally exciting and constantly in the news (e.g., <https://www.bbc.com/future/article/20230120-how-gut-bacteria-are-controlling-your-brain>), which is a major pedagogical benefit. The microbiology curriculum being created by the IMiL is designed to grab and leverage the imagination of the children, including those with special needs. We do not need to teach some of the traditional microbiology topics that may be less fascinating for children or less societally relevant. We can

teach just the most exciting material (the less exciting but nevertheless important material can be taught in specialist courses or at university), focus on the cherries on the cake, make school and learning exciting, and generate enthusiasm among pupils and teachers alike. To do this, the IMiL teaching resources include dedicated sections on the following:

- Descriptions of sampling campaigns and discoveries in exotic locations
- Personal microbiology and microbiomes
- Food
- Animals and pets
- Global activities and planetary wellbeing
- Astrobiology
- Class experiments
- Class excursions

Engagement. Children are concerned about the future of the world they will inherit: witness the international Friday school strikes to raise awareness about climate change and stimulate mitigating activities (https://en.wikipedia.org/wiki/School_Strike_for_Climate), and their interest and enthusiasm can be readily engaged by issues of sustainability, global warming and planetary health, and other societally relevant aspects of microbiology that the IMiL curriculum emphasizes. As also can be seen from the Strike for Climate movement, they enjoy interacting with others, especially via social media, and participating in international activities, interactions that can amplify their enthusiasm and motivation. To engage and stimulate this enthusiasm for group activities, the IMiL is developing family-friendly network projects and international citizen science projects (15).

Empowerment. An unusual characteristic of the TFs is that they are stand-alone, i.e., each can be understood or taught without knowledge of the others. This allows teachers to select which topics they consider to be of greatest interest and relevance to the children they are teaching, to mix-and-match TFs, and to follow a self-determined, not imposed, sequence of TFs. This empowers the teachers, and ultimately the pupils, by being able to select what they find the most interesting and relevant. And because TFs are stand-alone, new ones can be easily added and less interesting ones dropped, without impact on a curriculum structure, so the curriculum can evolve dynamically and organically. By providing feedback to the IMiL, teachers and children will help steer evolution of the curriculum, so they are not only empowered by being able to design their own curricula but also by influencing the creation of new materials.

Another aspect of empowerment of children is their ability to act themselves as educators (15), as agents of knowledge transmission among family members and friends and peer networks. The pupil or student centricity of the curriculum, the portrait galleries that expose fascinating personalities of microbes, and the family projects being designed

will all stimulate the natural tendency of children to transmit their newly acquired microbiology knowledge and feeling of empowerment.

Of course, the three Es, excitement, engagement, and empowerment, at the heart of the IMiLI school curriculum concept are core to catalyzing human learning at all levels, including high school, college, and university.

The particular characteristics of the IMiLI teaching resources include the following elements:

- Pupil or student centrality of the curriculum material (see below) which is designed to excite and engage the thirst for discovery
- Generic nature of TFs, the lessons, which provide the information used for multiple age groups and different teaching objectives
- Stand-alone nature of the TFs
- Emphasis on issues that excite children
- Emphasis on issues of personal and family interest and importance
- Emphasis on societally relevant issues
- Emphasis on the interconnectedness of things
- Emphasis on learning about stewardship and stakeholder responsibilities
- Creation of a new and comprehensive range of TF-specific class experiments that bring children in physical contact with the study objects and engage their excitement of hands-on activities
- Creation of a wide range of portraits of the movers and shakers of the microbial world, which will not only complement the TFs but also provide diverse activity opportunities (class discussions, competitions, creative arts, etc.)

These elements will represent a new type of child-centric teaching-learning ecosystem in which the children are directly and significantly involved in the teaching materials and teachers and pupils are empowered to express their stakeholder interests. The IMiLI concept may thus represent a new paradigm, or at least lead the way to the development of a new education paradigm.

While some of these characteristics are specific to teaching microbiology, others are equally applicable to other subjects and may serve as encouragement for interesting changes in the teaching of other subjects in school.

With minor adaptations (e.g., of the child-centric title pages of the TFs), the IMiLI resources will also serve for high school education, lifelong (classroom) learning, and curiosity-driven (Web-based) information demand by both children and adults.

Finally, this new way of approaching the subject of microbiology, from societal relevance and personal interest, may also stimulate changes in the way academics teach at least some elements of microbiology at university. Of course, excellent microbiology curricula are established in universities, so any influence IMiLI resources may have could range from relatively minor enrichment of existing programs, for example, through introduction of topics and aspects of societal relevance, the

issue of sustainability, and notions of stewardship and stakeholder responsibility, to the design of entirely new courses based on the IMiLI concept (Table 1), which differs from classical curricula in being child- or student-centric rather than subject-centric, and emphasizes the 3 Es.

Moreover, there is increasing pressure (often from students themselves) to introduce mandatory courses in climate crisis and sustainability and related topics for all undergraduate students (e.g., <https://www.theguardian.com/world/2022/nov/12/barcelona-students-to-take-mandatory-climate-crisis-module-from-2024>), and the IMiLI resources in nonspecialist language may provide both a model for such courses and a considerable amount of their content.

In the interest of full disclosure, I realize that some of the elements of the curriculum may not be original and that experts may consider my suggestion of a paradigm change to be pretentious. I am also acutely aware of the fact that I am not a teacher; my experience of teaching children is limited to 1 week of teaching 14 year olds when I was 18, and so I have little direct knowledge of the real world of the classroom. That said, I followed my son's school experience rather closely, formed opinions of what was good and less good, and reflected on what innovations might make a significant improvement. I therefore suspect that, collectively, the multiplicity of unusual aspects of the IMiLI teaching concept and resources make the strategy unique and may constitute a paradigm change. If these aspects are found to be useful changes in classroom practice, they may well influence future development of the teaching of other subjects.

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