AMERICAN SOCIETY FOR MICROBIOLOGY | JMBE Journal of Microbiology & Biology Education

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| Perspective

Developing microbiology literacy in biology education college: future teacher candidates

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ABSTRACT Recently, several articles have reflected on the existence of microorganisms in supporting the life and health of living creatures as the beginning of the emergence of microbiology literacy. In the curriculum, understanding the activity of microorganisms has been studied from pre-school, elementary school, and middle school to college. The presence of microorganisms is often associated as a cause of disease. As a result, most students know the negative impact of microorganisms but have not discovered the fundamental role of microorganisms in their lives. Special attention needs to be given as a form of effort to strengthen microbiology literacy. Several studies state that students have an important role in disseminating the concept of sterilization, maintaining a safe distance, and using masks as generally applicable protocols during the pandemic. Therefore, with the aim that microorganisms have an important role, both directly and indirectly and to curb negative perceptions of microorganisms, we propose microbiology competencies among biology education students, who are future teaching candidates. This article identifies the complex challenges of 21st-century microbiology learning and the OECD framework. This approach includes the use of pedagogical interventions with the main objectives: (i) knowledge (to teach fundamental microbiology knowledge, (ii) skills (to increase awareness in recognizing and solving real-life problems), and (iii) attitudes and values (to explain the contribution of microbiology in supporting life).

KEYWORDS microbiological literacy, microbiology literacy, microbial knowledge, microbial awareness, microbial contribution, microbiological sustainability

Microbiology introduces students to the diversity of microbes. Most of them tend to know that microbes can cause infectious diseases (1), foodborne illnesses (2), and pandemics (3). Furthermore, students only know about the negative impacts of microbes but have not yet discovered the fundamental role of microorganisms, both on Earth and the role of microbes in life (4). During the coronavirus disease 2019 (COVID-19) pandemic, negative perceptions were found to be developing in society (5). This condition is supported by the discovery of infections in the healthcare sector as a significant problem (6), increasing cases of antibiotic resistance (7, 8), doubts about vaccines (9), the emergence of several infectious diseases such as the Zika virus (10, 11), and the influence of climate change on the spread of viruses (12, 13). Special attention needs to be given to strengthening microbiology in the national curriculum.

Providing relevant and meaningful academic services to students will help students form knowledge. Students need to be equipped with critical thinking skills to adapt to unfamiliar situations due to the increasing rate of change, and increasingly intensive work complexity, and to prevent the spread of misinformation (14). Microbiology literacy in society is needed as a basis for personal decision-making. At the next level, microbiology literacy has a role as a stepping stone in the development of government regulations, business development (15), green economic recovery (16), biofuels (17), environmental sustainability (18–20), improving public perception (3, 21), sustainable

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The authors declare no conflict of interest.

Received 3 March 2024
Accepted 7 June 2024
Published 8 July 2024

feedstocks (22), circular economy (23), sustainable development goals (18), healthy life (24), and healthy buildings (25). What is no less important is that microbiology literacy also develops bioethics (26) and has an influence on future careers (27).

Information literacy has important potential for optimizing the use of available data and information while turning students into lifelong learners (28). The discussion of microbiology literacy in the last few decades has become a milestone in the launch of the International Microbiology Literacy Initiative. Furthermore, this community is working to create teaching resources to shape the microbiology curriculum in schools (29). The program involves hundreds of committed microbiologists with a worldwide reach. Based on search results on the Scopus database, during 2001–2016 in 26 fields of study, there were gaps found in the search for information related to microbiology literacy (28). This is the basis for the author to propose microbiology literacy competencies for prospective teachers, guided by the OECD so that they can keep pace with the acceleration of information in the field of microbiology.

Microbiology literacy is part of scientific literacy. In 2014, it was reported that microbiology learning was carried out through the involvement of scientific investigations, with problem learning strategies, involving computing and laboratory inquiry (30). In connection with sustainable development activities that have emerged to answer the needs of the present without compromising the capabilities of future generations, a series of studies on the decline of several features of the biosphere, one of which is microorganisms, was carried out (18). This paper proactively promotes the exploitation of microbiological discoveries for human benefit. Only in 2019, a paradigm for microbiology literacy emerged (15), and efforts to introduce it into the school curriculum began (15). Since the emergence of comprehensive publications regarding the urgency of microbiology literacy, this field of study has begun to receive attention to involve more parties and communities.

This paper was written as a basis for developing microbiology literacy in biology education college and future teacher candidates following 21st-century skills development and the OECD framework. Microbiology learning in the 21st century has developed and covers a broad scale, about higher order thinking skills (31), mastery of literacy skills (29), life skills (32), involvement of technology (33), and leads to sustainable development goals (18, 23). Learning microbiology leads to the mastery of transformative competencies, namely competencies that aim to change society and shape the future (34). The OECD framework consists of knowledge, skills, attitudes, and values. In this paper, we propose three competency studies to measure microbiology literacy (Fig. 1), consisting of (i) knowledge (fundamental microbiology knowledge), (ii) skills (awareness in recognizing and solving problems relevant to microbiology), and (iii) attitudes and values (how microbes can be used for the benefit of humans) (35). The OECD states that disruptions in education during the pandemic have propelled digitalization into a significant leap and emphasized lifelong learning. The OECD framework on microbiology literacy would assist prospective teachers in understanding what needs to be mastered, thereby facilitating a shift from knowledge distribution-oriented learning to lifelong skill development (36).

Students and fundamental microbial knowledge

Microorganisms can be found in every part of the environment (25, 37, 38), even in very clean health facilities or on space stations (39). The biodiversity of microorganisms should be addressed positively. Some microbial species do not cause disease in humans, but have an influence on individual health, play a role in making food, and support healthy environmental conditions (21). A study has proven that the diverse microbial communities in house dust components do not harm health (40), and exposure to these microorganisms during early childhood influences the development of the child's immune system (41). A person's lack of exposure to immunoregulatory microorganisms has led to an increase in the emergence of physical and mental illnesses in modern society (42).

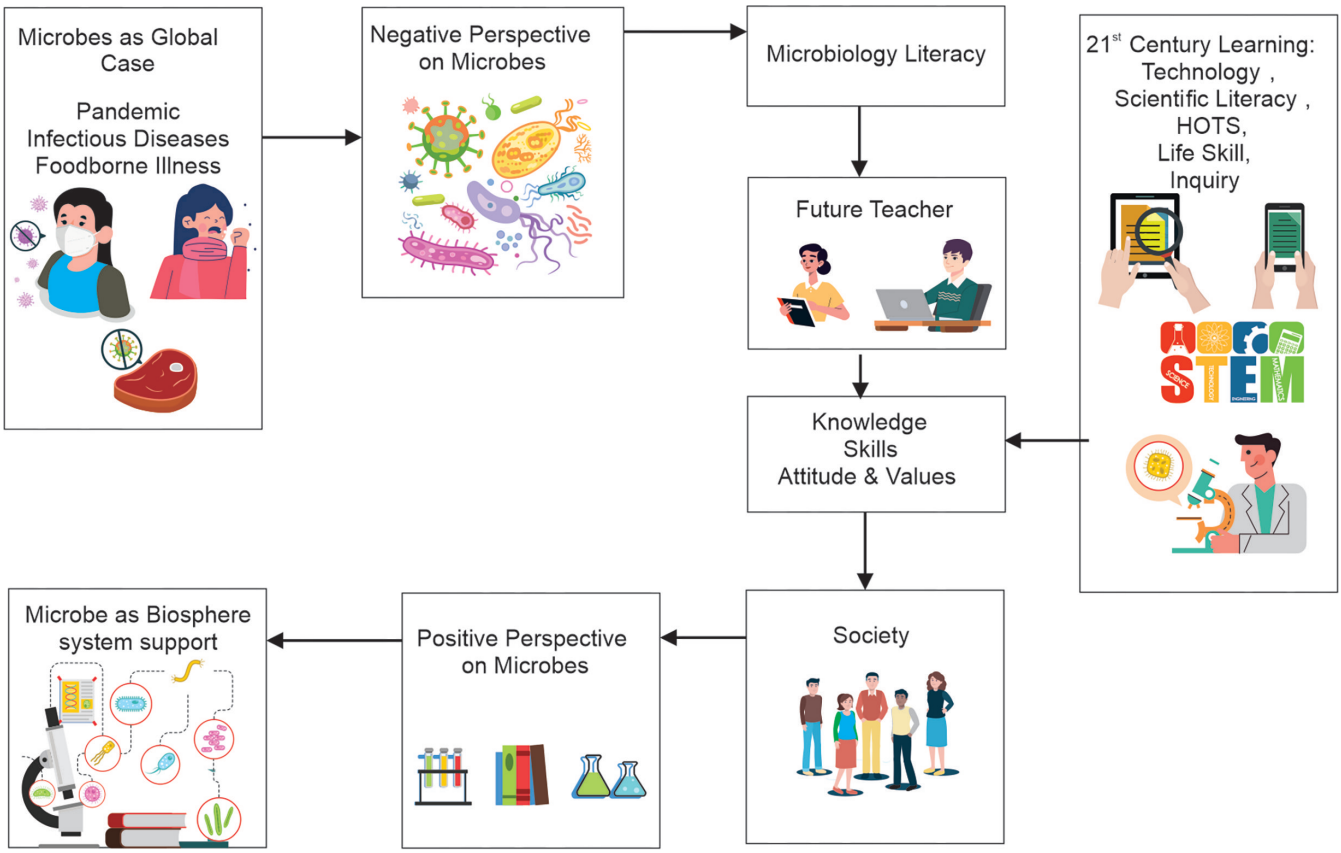

FIG 1 Microbes in society are often considered negative and are linked to causing pandemics, infectious disease infections, and foodborne illnesses. Microbiology literacy must be mastered by prospective teachers without ignoring other supporting literacy aspects such as technological literacy and scientific literacy. Microbiology literacy refers to understanding knowledge, skill mastery, as well as attitudes and values so that it can introduce the public to the positive side of microorganism as life support.

The phenomenon of other paradigms in dealing with microorganisms is important for students. Fundamental microbiology knowledge can direct students to be involved in their learning process and integrate the context of what they learn, which will then be useful in decision-making. Components in the knowledge aspect include facts, concepts, principles, laws, hypotheses, theories, and scientific models (43). Students' knowledge becomes the basis for them to understand the world, including where future science learning will be built (44). The OECD learning framework states that knowledge consists of (i) disciplinary (as material for developing new abilities), (ii) interdisciplinary (the capacity to think across disciplinary boundaries and connect studies), (iii) epistemic (knowledge about scientific disciplines to facilitate the expansion of knowledge), and (iv) procedural (knowledge to understand how a series of steps are taken to achieve a goal) (34).

One of the main objectives of learning microbiology is to equip students with basic knowledge, which in this study, can be referred to as fundamental microbiology knowledge. Knowledge (5, 45) is an important aspect of microbiology literacy, and its exploitation is needed to equip students to respond to relevant problems. Knowledge of microbiology is growing very quickly along with advances in science in reaching it. Microbiology literacy is open, so students must have good adaptation in dealing with changes in microbiology knowledge that are developing significantly. In fact, human pathogens account for less than 1% of the total number of microbial species on the Earth (46). Knowledge is the main weapon for prospective teachers to master in order to disseminate about the role of microbes in the biosphere to the community.

Students must learn to increase awareness in recognizing and solving problems relevant to microbiology

The pandemic situation has led students to strengthen the microbiology curriculum globally. Health practices and their dissemination are increasing due to awareness. The COVID-19 pandemic has forced students to adopt healthy living behaviors such as (i) using hand sanitizer which aims to stop the rate of microbial growth on the hands (47) as an aseptic working principle, (ii) use of masks and face shields to prevent virus transmission (48), (iii) maintaining distance, avoiding crowds, and limiting mobility as a form of preventing viral spread (49, 50), (iv) body immunity to virus exposure (51) and vaccination developments (52, 53). Students' knowledge and experience of microbiology have an impact on personal decision-making.

However, the university opted for distance learning during the pandemic, making it challenging to teach laboratory skills online. We concur that, in the enhancement of skills, students can refer to seven basic laboratory competencies, including data analysis, scientific writing skills, proper handling and disposal of laboratory materials, discipline-specific techniques, measurements, laboratory safety, and personal protective equipment, as well as interpersonal and collaborative skills (54). The presence of virtual laboratories in education also brings about transformation, making them valuable skills that complement learning objectives (55). It is further elucidated that virtual laboratories can be explored as Massive Open Online Courses to ensure the continuity of the teaching and learning process under various conditions, providing an alternative training option from home. All skills synergize with knowledge, attitudes, and values in microbiology literacy to increase awareness in recognizing and solving real-life problems.

Students must be able to explain the contribution of microbiology to life

Human life cannot be separated from and is influenced by the presence of microorganisms (21). Microorganisms contribute to food supply (56), affect public health (57), support the creation of a healthy environment (21), biosphere system support (29), support nitrogen fixation processes (58, 59), carbon fixation processes (60), decomposition processes (61), role in biogeochemical cycles (62), plays an important role in biotechnology studies (63), bioindustry and renewable energy (22), antibiotic production (64), and bioremediation (65–70). Knowledge, skills, and experience have an impact on forming a person's attitudes and values in studying microbiology.

The student's paradigm regarding the predominantly negative contribution of microorganisms is gradually shifting through the enrichment of knowledge concerning the biodiversity of microorganisms, facilitated by experiential learning (71) and technology-based education (72). A thorough enrichment of biodiversity knowledge will lead to the recognition of microbiology's pivotal role as a crucial aspect in supporting the biosphere's equilibrium.

CONCLUSION

Microbiology is a rapidly advancing field of science, which requires steps to overcome the challenges of microbiology education in the 21st century. Prospective microbiology teachers will design and engineer learning environments with professional intervention, that require good microbiology literacy. A strategic role is required from microbiology researchers to extensively publish research findings, serving as the foundation for educators to update our materials with the latest knowledge. If possible, collaboration is needed so that prospective teachers' knowledge develops at the speed of the discovery of new knowledge, especially in the field of microbiology. Through this paper, we propose an approach that can be used in pedagogical interventions to measure microbiology literacy including (i) knowledge, aimed at imparting fundamental microbiological knowledge, (ii) skills, aimed at enhancing awareness in identifying and solving everyday life problems, and (iii) attitudes and values, serving to elucidate the contributions of microbiology in supporting life. In the future, instruments need to be

developed so that they can specifically be used to measure microbiology literacy in the 21st-century learning.

ACKNOWLEDGMENTS

We acknowledge Universitas Negeri Malang for their support under Postgraduate Grant 3.4.93/UN32/KP/2024, and we highly appreciate their professional text editing service.

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