Special Series: Scientific Literacy

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Developing Science Literacy in Students and Society: Theory, Research, and Practice

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The subject of scientific literacy has never been more critical to the scientific community as well as society in general. As opportunities to spread misinformation increase with the rise of new technologies, it is critical for society to have at its disposal the means for ensuring that its citizens possess the basic scientific literacy necessary to make critical decisions on topics like climate change, biotechnology, and other science-based issues. As the Guest Editors of this themed issue of the *Journal of Microbiology and Biology Education*, we present a wide array of techniques that the scientific community is using to promote scientific literacy in both academic and nonacademic settings. The diversity of the techniques presented here give us confidence that the scientific community will rise to the challenge of ensuring that our society will be prepared to make fact-based and wise decisions that will preserve and improve our quality of life.

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EDITORIAL

Scientific literacy can be defined in multiple ways, from how an individual processes scientific facts and concepts and interprets scientific data to how a community collectively interacts with scientific knowledge and processes. Scientific literacy skills are incredibly important for people to develop: whether they are trained scientists or not, people encounter issues pertaining to science frequently in their daily lives. In modern times, people are continually exposed to news stories about climate change, energy production, and health, exercise, and medicine, not to mention the 2019 coronavirus disease (COVID-19) pandemic. By investigating scientific literacy skill development and designing classroom or outreach activities to promote scientific literacy skills, we as science educators can help improve student and societal scientific literacy, which can lead to more-informed decision-making by individuals and societies. Whether the students in our classrooms are science majors or not, it is critical for them to develop science literacy skills and promote science literacy in their communities.

As scientists and science educators, we are passionate about promoting the science literacy of both our students and our society. The 2023 JMBE themed issue on "Scientific Literacy" will examine this concept from multiple angles, from theoretical frameworks to research on the impact of literacy interventions to practical tools for developing scientific literacy in diverse groups of learners. Here, we analyze a portion of these articles, sorted by major themes in scientific literacy that are represented in this special issue.

Theoretical frameworks that inform the development of scientific literacy

At the core of all great research studies is a theoretical framework. However, for a topic as complex as scientific literacy, how do you determine which framework is appropriate for your particular take on scientific literacy? Tenney et al. identified three different learning theories, information processing, constructivism, and sociocultural theory, and they discussed the conceptualizations of science, technology, engineering, and math (STEM) literacy and offered insightful perspectives on

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how to conceptualize what it means to be STEM literate (1). And, if you envision science literacy to be larger than these three theories, and to extend outside of the classroom, Elhai here helps readers redefine science literacy at the community level (2). These perspectives may be valuable to others as they work to conceptualize what science literacy means in their own circumstances.

Scientific literacy in the context of microbiology, cell biology, molecular biology, immunology, disease ecology, and other disciplines

We cannot forget that science is at the heart of science literacy, and part of science literacy is knowing basic science. In line with current scientific challenges related to public health, Ricci et al. (3) and Mixter et al. (4) provide ideas for teaching and learning about infectious disease, through art (as described here by Ricci et al.) and through system-level change and collaboration among novice and experienced educators, professional societies, and policymakers (as described here by Mixter et al.). Access to microbiology is also expanded, with Newman et al. presenting here a novel card-sorting task involving visual literacy skills (5) and Joyner and Parks outlining how to develop a public data presentation and an epidemiological model based on current events (6).

Pedagogical practices, including effective classroom tools

Undergraduates are prosumers, consuming and producing scientific information at the same time. This requires assignments to be built on each other in a scaffolded or multistep format. Joyner and Parks present a multicourse approach using modern pedagogical methods to promote communication and data and information literacy in STEM students (6). Similarly, Rholl et al. described how they let students engage with current events in interactive, multiweek activities that increase student motivation and agency (7). Sarvary and Ruesch describe how undergraduates can be taught through a multistep framework to become critical consumers of scientific evidence in a single laboratory session. These two authors have used and assessed a variety of active learning methods in the past decade to help students find, evaluate, comprehend, and cite scientific information (8). With the rise of social media, undergraduates need to be taught how to responsibly share information using these constantly changing platforms. The Social Media Reflection assignment has been successfully used in both lower- and upper-level courses, helping students assess scientific claims and fight misinformation (9).

Student understanding of the nature of science, quantitative literacy skills, and science communication

There is an intricate connection between how students understand scientific concepts, scientific process, and primary scientific data and how they are able to communicate about these topics with each other and with those outside the scientific community (10) and in their future careers (11, 12). This is critically important for our science students who will interact with patients as future health professionals (11). One way in which students can engage with a mix of scientific facts, processes, and data is via the primary scientific literature. Developing the skills to read and understand the primary scientific literature is difficult (13). Authors in this special issue present how student skills in analyzing data in the primary scientific literature can be improved via graphical abstract assignments (14) and annotations (15, 16), as well as by engaging in peer review (17). Beyond developing their own understanding of the science, engaging with the primary scientific literature is important for our students, as they can utilize the literature as a tool for science communication with nonscientist audiences (18). Conversely, we can utilize popular texts intended for the public in our science classrooms in order to promote science literacy and new insights about socio-scientific issues (19). In addition to specific forms of literature, empathetic and relational conversations about science are another tool by which students can build both their knowledge of the science and their abilities in science communication (10).

Community science literacy and outreach

Science literacy skills are required for everyday decision-making and are often applied by nonscientists. These nontechnical audiences are able to understand scientific evidence using primary literature (18) and develop interest in science using art (3). Attitudes toward science and trust in scientists became especially important during the COVID-19 pandemic. Mixter et al. discuss immune literacy at the individual and societal level and call for a system-level change to build this important skill not only in classrooms but also in the community (4). Service learning and community engagement can help with this effort (10).

Impacts on learning and assessment in the classroom or the community

By creating students and communities that are more scientifically literate, we can set the table for increased opportunities for these groups to learn and understand science, to translate that knowledge into making positive changes in society, and to potentially join the STEM workforce. Several articles (3, 4, 7, 16) consider new approaches for using scientific literacy as a vehicle for enhancing student appreciation for specific STEM fields. Other articles focus on ways that instructors can better assess the progress that students are making toward developing both stronger levels of overall scientific literacy and mastery of particular course material (8, 13). Finally, when students gain practice in argumentation about authentic ethical issues in research, they are better prepared to collaboratively engage with diverse communities about these challenging issues (12). There is a dynamic conversation taking place within the scientific education community on ways to translate increases in scientific literacy with gains in overall learning objectives in

a variety of STEM disciplines. This conversation promises to continue to evolve best practices for reaching this goal among both traditional students and "citizen scientists" in society.

Inclusive approaches and removal of barriers to scientific information

The scientific community is becoming more cognizant of the need to consider equity and inclusion and incorporate them into strategies for improving scientific literacy in the classroom and across society. This issue explores the use of laboratory course elements as drivers of equity-based STEM education (20) as well as the development of empathetic communication skills as an effective means of reaching all members of the community regardless of their previous experiences with science and potential exposure to scientific misinformation (10). Within the classroom, different research groups are exploring how to develop literacy-based assignments that either use unconventional and more accessible means to bring new students into an exploration of science (3, 14) or provide learning support tools that make engagement with scientific literature more accessible to all (18). A society cannot improve its overall level of scientific literacy without finding ways of making scientific knowledge accessible to all of its members, and the work presented in this issue provides a variety of approaches toward this goal.

Conclusion

This issue could not be coming out at a more critical juncture in our society, as the scientific community struggles to find ways to battle both disinformation campaigns about how science is done and presented and the preconceived intimidating notions that many hold about the accessibility of science to the masses. Issues such as climate change, vaccination, and environmental conservation cannot be solved by a scientifically illiterate society. As science continually evolves, so must our understanding of how to best communicate science across ever-changing platforms and audiences. It is our hope that the ideas presented in this issue will inspire both the current scientific community and future generations of scientists and teachers to continually work to make science as accessible, learnable, and exciting as possible to citizens of all ages and backgrounds.

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We are grateful to the *Journal of Microbiology and Biology Education* for advancing this vital scientific literacy conversation and for allowing us the opportunity to help assemble this exciting collection of current work on this topic. We hope that these articles will engender in you the desire to join the conversation and help to keep moving our understanding of best scientific literacy practices forward.

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