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Immune Literacy: a Call to Action for a System-Level Change

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Immune literacy—the ability to hear, learn, read, write, explain, and discuss immunological content with varied audiences—has become critically important in recent years. Yet, with its complex terminology and discipline-specific concepts, educating individuals about the immune system and its role in health and disease may seem daunting. Here, we reflect on how to demystify the discipline and increase its accessibility for a broader audience. To address this, a working group of immunology educators from diverse institutions associated with the research coordination network, ImmunoReach, convened virtually. As a result of these discussions, we request a call to action for a system-level change and present a set of practical recommendations that novice and experienced educators from diverse institutions, professional societies, and policymakers may adopt to foster immune literacy in their classrooms and communities.

KEYWORDS immunology education, science literacy, ImmunoReach, a community of practice, evidence, jargon, concepts, curriculum design, policies, frameworks

PERSPECTIVE

We specifically define immune literacy as an individual's ability to hear, learn, read, write, explain and discuss immunological content with diverse audiences. This is distinct from the biological concept of "immune literacy," which is defined as the ability to read, write, and edit the adaptive immune response in translational medicine (1). Although immune literacy is a significant component of science and health literacy, it is also exclusive, because it involves discipline-specific terminology and concepts. Comprehension of immunology-based messaging (popular press articles, social media posts, scientific literature, and public policy) may require a basic understanding of immunological techniques and research models. Immune literacy is often considered synonymous with vaccine literacy. Whereas vaccines and vaccine literacy are great examples of immunology-related topics that have reached a broad public audience, there still exists a significant need to effectively disseminate immunological principles beyond those associated with vaccines. General knowledge of the immune system is important for leaders to be able to establish sound policies regarding public health, environmental health, curricular standards, and many other societal challenges.

At an individual level, immune literacy is required for a myriad of health care-related decisions such as nutritional choices that affect immunity, cancer immunotherapy, autoimmune disease therapy, hypersensitivities, and emerging infectious diseases, as well as for understanding the impacts of climate change on human health and One Health-related actions and policies. At a societal level, immune-literate people can advocate for evidence-based policies and can encourage others to vote for funding to support science at the local, state, national, and international levels. Increased immune literacy would have broad implications for combatting the spread of misinformation within society and would create a feedback loop to increase the likelihood that individuals will follow public health recommendations. With proper education, leading to

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immune literacy, individuals would be more likely to intervene in the dissemination of misinformation and much less inclined to share misinformation because they are well informed (2). This would then have the potential to decrease the amplification of misinformation pertaining to the use of vaccines or therapeutics to combat endemic and emerging infectious diseases. With greater understanding of the reasoning behind specific health recommendations, such as vaccination, an improved quality of life across the population may be realized through decreased morbidity and mortality and by limiting the negative economic impact associated with disease (3). These concepts are widely supported in the public health-based literature, where immunization campaigns have abolished diseases, such as smallpox, from the face of the earth (4).

Here, we acknowledge four curricular challenges to immune literacy, along with recommendations to alleviate them. These recommendations are intended to be helpful for novice and experienced educators and, ideally, could be discussed and adopted by a range of institutions, professional societies, and policymakers to foster immune literacy in their classrooms, communities, and beyond.

CHALLENGE #1: PROBLEMS WITH IMMUNE LITERACY PARALLEL THOSE WITH SCIENTIFIC LITERACY

Problems encountered when trying to foster immune literacy mirror those associated with scientific literacy, which in turn can affect public health behaviors (5). Historical problems that one might think had been resolved during the 1918 influenza pandemic surfaced again with COVID-19, causing significant challenges for public health planning (6, 7). Mass campaigns were launched to reeducate the public regarding the benefits of vaccination (8). One thing that became abundantly clear was that uncertainty, fear, lack of knowledge, and lack of trust in scientific expertise worked against public health efforts to curb the pandemic (9–11). Politicization of science (12, 13), as well as religious and cultural beliefs (14), may affect how people perceive immunological content. The problem is further complicated by social media, which, like any other technology, has its strengths and challenges. Whereas a retweet fosters the rapid spread of information, that information can be misleading if it lacks the appropriate scientific scrutiny (15, 16). Identifying and labeling such misinformation is challenging because much of this information is shared within tight-knit, trusted social networks. This can influence public attitudes and preconceptions coming into the classroom and impact what an instructor is comfortable teaching (17).

With this, the reliance on experts to employ scientific knowledge during this dialogue is also critical. It is easier to garner trust if individuals understand the basic nature of science, the concepts underlying scientific discourse, and the effective processes of science communication. However, for most individuals in society, these are unfamiliar concepts, and it is essential that educators and scientific experts acknowledge this. As Osborne and Pimentel note in a recent publication, educating students about science is critical, but it is even more important to equip students with the knowledge to critically evaluate claims so they can become the "competent outsiders" who can make informed decisions about themselves, their families, and the public at large (18). This is especially important for a rapidly evolving field like immunology, in which scientific uncertainty can be profound, and science can take time to provide explanations.

RECOMMENDATION #1: ADOPT AN INCLUSIVE, SOCIO-SCIENTIFIC APPROACH AND MAKE AN INTENTIONAL EFFORT TO TRAIN "COMPETENT OUTSIDERS" IN IMMUNOLOGY

Use of a socio-scientific issues approach to pedagogy (19, 20) may assist students to share their worldview and develop competencies that will enable them to understand key immunological concepts associated with contentious cultural and societal issues that are often related to immunology. This issue-based teaching approach encourages classroom discourse, coupled with active questioning and evaluation of social arguments, after exploring authoritative resources outlining the immunological concepts. In addition, it is advisable that trusted institutions take the lead on science communication, especially through social media, since some individuals are more likely to associate those institutions with credibility and trust, as opposed to individuals, even if these individuals are trusted within the scientific community (21). An inclusive approach to scientific communication adopts a two-way communication model, where listening and learning from each other takes precedence over preaching. This approach is based on the principle that nonscientific knowledge, for example, cultural or experiential knowledge, is at par with the scientific knowledge (22). This model of scientific communication invites the public into problem solving, which is likely to increase the buy-in and assist in devising a common solution to global problems using a grassroots approach.

Continuous integration of immunological concepts across the K-12 education system is essential, coupled with implementation of instructional strategies that help students develop critical thinking skills (23). Going beyond simply teaching immunological facts and, in addition, focusing on how the scientific process works will set students up to critically evaluate politicized or misrepresented information. These critical thinking skills are indispensable for the ability of individuals to navigate misinformation on social media and effectively refute claims that represent politicized immunological perspectives. Here, we propose that Osborne and Pimentel's three-step heuristic to evaluate scientific information can be especially important for nonscientists and beginner learners of immunology (18). This three-step heuristic is explained below, with examples from immunology.

Step 1: How credible is the source of the evidence?

This step is where the audience is encouraged to think about conflict of interests, any biases or conflicts that may exist in reporting the evidence and whether the sources of information and funding have been adequately cited and acknowledged.

Step 2: Is the evidence provided by a person/institution that possesses expertise and experience to vouch for the claim?

Step 2 addresses how the audience can be encouraged to think about credentials, reputation, and experience of the person/institution making the claim.

Step 3: How strong is the evidence?

For step 3, the audience is encouraged to think critically and participate in the scientific consensus on an issue. A public health-based approach to evaluate evidence can be adopted, and the audience can be exposed to the following terms by using examples: (i) systematic reviews and meta-analysis versus nonsystematic reviews; (ii) clinical versus epidemiological versus experimental studies; and (iii) different types of observational studies (24, 25). Examples of immunology-based claims that may serve as starting points for productive discussion, and can be evaluated according to the above-mentioned heuristic could include the following: (i) vaccines cause autism, (ii) vitamin C boosts immunity, and (iii) the COVID-19 vaccine is unsafe for breastfeeding individuals.

CHALLENGE #2: THE INHERENT NATURE OF IMMUNOLOGY IS COMPLEX AND INVOLVES EXTENSIVE DISCIPLINE SPECIFIC TERMINOLOGY

Immunology is a discipline that requires individuals to master a large number of complex concepts, with an abundance of discipline-specific terminology. Navigating the intricate pathways and systems that constitute the immune system, while maintaining a higher-level appreciation of the system as a whole and focusing on key conceptual paradigms, can be a challenge for both novice and experienced instructors. The challenge can be even more daunting for instructors who are not trained as immunologists. What is important in immunology? How thoroughly should a topic be covered? Which terms are important? For example, is a knowledge of all cytokines and their functions critical for an undergraduate immunology student? These are some of the questions that instructors may face while approaching course design.

RECOMMENDATION#2: USE A CONCEPT-FOCUSED INSTRUCTIONAL DESIGN THAT CATERS TO THE AUDIENCE

The American Association for the Advancement of Science (AAAS) launched a curriculum reform statement called "Benchmarks for Science Literacy" under the umbrella of Project 2061 that outlines what all students should know and be able to do in science, mathematics, and technology by the end of grades 2, 5, 8, and 12. One of the benchmarks noted in this curricular reform statement is to "avoid the excessive use of technical language and jargon, both to reduce the sheer burden on students and to prevent knowledge of vocabulary from being mistaken for conceptual understanding" (26). The same benchmark to focus on conceptual depth versus breadth was noted in the "Vision and Change in Undergraduate Biology Education: a Call to Action" report published by the AAAS, which identified five key concepts for life science education that undergraduate students must understand: (i) evolution; (ii) pathways and transformation of energy and matter; (iii) information flow, exchange, and storage; (iv) structure and function; and (v) systems (27). These concepts have stood the test of time over the last decade.

How can we, as educators, leverage these statements for immune literacy? Educators that can list a clear, immunology-specific, measurable learning outcome (28) can classify that learning outcome under one or more of the above-listed concepts in biology. This approach to align learning outcomes with the key concepts for K-12 (29) or undergraduate (27) life science education would allow educators to adopt a mindful, backward design approach to lesson planning and assessment. This approach should also enable them to focus on conceptual depth and not just the breadth covered with a myriad of immunological topics (30, 31). Once the conceptual focus is clear, the example learning outcomes can be approached in a classroom, based on the extent of depth that an instructor would like to cover. An example for this approach is noted in Table 1. With such an approach, the intent is to make interdisciplinary connections obvious for immunology, so that educators can more effectively explain a key biological concept (e.g., structure and function) with an immunology-focused example. With this concept-focused approach, immunology-focused content can be provided earlier in a program of study in addition to typical upper-level undergraduate biology courses. A community-based approach to develop such a framework for immunology is currently under works by the ImmunoReach Research Coordination Network (RCN) (32; unpublished data).

Although the above-mentioned approach focuses on concepts, educators and students often want to focus on the applications of immunology (e.g., immunotherapies, vaccines, transplantation, coevolution of host and pathogen, etc.) and on newer scientific discoveries (e.g., a newly discovered lymphocyte subset), which are key to making the content exciting and engaging (33). The above-mentioned conceptual approach does not dissuade educators from discussing the exciting content, but rather invites them to use it as the starting point and then discuss the topic in greater depth using the key concept as a framework. When done intentionally, an instructor can maintain focus on the key concept, gradually introduce the new terminology, and then design assessments to measure what is truly important in a lesson plan.

Discipline-specific terminology is an integral part of immunology and that is why learning the terms and using them in the correct context is an essential part of progressing from novice to expert in the discipline. The COVID-19 pandemic raised awareness of many immunology and public health terms in the

TABLE 1
Examples of core concepts with immunology-focused learning outcomes for varied educational settings

Core concept(s)	Alignment	Learning Outcome examples
Structure and function	• Vision and Change Report (AAAS, 2011); Core Concept • National Research Council. 2012; Core ideas in the life sciences	• Describe the impact of spleen, appendix, tonsils, or thymus removal on an individual's immune response. • Distinguish between immune cells based on shape, size, and staining patterns. • Discuss how the granule content in neutrophils, eosinophils, basophils, and mast cells relate to their immune function.
Evolution	• Vision and Change Report (AAAS, 2011); Core Concept • National Research Council. 2012; Core ideas in the life sciences	• Explain how microbes and hosts dynamically coevolve. • Explain how the sickle cell anemia-associated allele is advantageous in certain human populations. • Describe how B-lymphocyte specificity evolves over the course of a primary immune response.

public, for example, "antigen" and "RT-PCR" (34, 35). This is where knowing your audience is crucial. Which terms are students already familiar with, and are they able to use those terms in the correct context? What misconceptions or preconceptions exist among the student population? Previous research by Zukswert et al. (36) has shown that students often struggle with describing abstract molecular structures (e.g., epitope) compared to terms that were in use in everyday English vernacular or in biology (e.g., dominant), terms that are related to the description and the transfer of information (e.g., transcription), or terms related to the practice of science (e.g., experimental control) or that pertained to organelles (e.g., chromosome) or cellular and biological processes (e.g., mutation). Immunological content is cellular and molecular in nature. However, a lot of the cells and molecules important in immunology (e.g., cytokines [such as interleukin-4], chemokine receptors [such as CXCR4], or various cell determinants [e.g., CD4]) can be introduced in the context of a more general paradigm that fosters understanding and not as a simple list of terms to be memorized. Exposing students to an overwhelming number of new cellular and molecular terms all at once can be daunting. Rather, instructors may start with explaining the English or biological vernacular and then gradually introduce the cellular or molecular paradigms that use a limited set of terms specific to immunology. A survey to preassess the knowledge of an incoming student cohort with a term- and concept-based survey can help an educator gauge what the students already know and then design lesson plans to address the knowledge gaps of the target audience and to eliminate key misconceptions, while gradually introducing new terminology.

CHALLENGE #3: LACK OF TEACHER SUPPORT AND PROFESSIONAL DEVELOPMENT OPPORTUNITIES

Immunology has traditionally been viewed as a difficult subject to teach even at the professional school level (37). Without formal training in immunology, instructors may feel ill prepared to cover immunological concepts in their courses. Yet, the need to expand the integration of immunology into STEM curricula exists due to increasing societal needs to explain how the immune system impacts health and causes disease and how immunological principles are being harnessed to improve human health. Even if the intent is there, educators may lack the confidence or the time to become experts in immunology. To further complicate the problem, immunology as a discipline is rapidly evolving, with new scientific discoveries being made at a rapid pace. This requires educators to continuously study the field and to update their approach to educating others.

RECOMMENDATION #3: TAP INTO AN INTERDISCIPLINARY COMMUNITY OF PRACTICE

Anthropologists Jean Lave and Etienne Wenger coined the term "community of practice" in the context of learning theory to refer to a community that acted as a living curriculum for apprenticeship (38). Since then, the term has been widely used in various contexts, including educational settings. It is defined as a "group of people who share a concern or a passion for something they do and learn how to do it better as they interact regularly" (39). A shared field of study and practice can bring individuals together as a community. This formed the basis of a community of practice called "ImmunoReach" (40, 41). ImmunoReach started out as a community of primarily immunology educators. Although immunology education remains the main focus of this network, recent funding from the National Science Foundation allowed for extended interdisciplinary collaborations with educators who are not specifically trained as immunologists. The intent was to work together to identify common language that allows us to put immunology into a broader biological context. For example, evolution is a cross-cutting concept that can be discussed at a population level, as well as at a molecular level in the context of effective antibody response. Similarly, immunology can serve as a platform to address systems level questions, as noted previously by Stagaman et al. (42). The extent of details can vary based on the instructor's expertise and student's prior knowledge. By making such interdisciplinary connections obvious for their students, educators can bring immunology-specific content into their introductory biology classrooms. The key intent behind such a community of practice is to identify common language; develop mutual appreciation for each other's discipline; problem solve; share information, resources, and experiences; empower and build confidence; discuss new developments in the field of immunology and education; document projects; and continuously learn from and support each other. Empowering instructors to design and deliver content focused on interdisciplinary immunology-focused learning outcomes is an important consideration in looking at ways to enhance immune literacy across diverse educational contexts. Such communities of practice are vital to increasing access to immunological content and thereby fostering immune literacy. They may also provide seeds for new interdisciplinary scientific discoveries and educational innovations and provide excellent opportunities for faculty professional development and lifelong peer support.

CHALLENGE #4: CURRICULUM DESIGN-RELATED LIMITATIONS FURTHER COMPLICATE ACCESS TO IMMUNOLOGY EDUCATION

Immunology is typically taught as a graduate-level course, as a one-semester upper-level undergraduate course, or as a module, for example, in a microbiology or physiology course. Immunology at the undergraduate level predominantly caters to premedicine and pre-allied health disciplines. Immunology is not a typical course taught at two-year colleges, with the exception of Medical Lab Technologist programs. The inclusion of immunology-related topics at an introductory level in undergraduate biology curricula is limited (43, 44). A survey of 2- to 4-year transfer pathway curricula gathered from faculty within the ImmunoReach network at eight institutions (Minnesota State system, Johnson County Community College, Labette Community College, Frostburg State University, Washington State University, the University of Dubuque, North Dakota State University, and the University of Alabama at Birmingham) notes that immunology is not one of the courses included in the transfer pathway curricula. Similarly, immunology is not one of the priority subjects for K-12 teaching licensure and therefore is not translated into topics taught at the K-12 level. As a result, faculty-hiring committees at these institutions are not likely to emphasize immunology-related expertise, further limiting the inclusion of immunology related topics at an introductory level. The existing conceptual frameworks for the K-12 educational system (e.g., the one developed by the National Research Council of the National Academies [29]) or The Vision and Change for undergraduate life science education (27) emphasize broad biological concepts. The curriculum guidelines proposed by the American Association of Immunologists (AAI) for undergraduate education are immunology specific (45). Accreditation requirements may further limit the inclusion of immunology-related topics into the curriculum. ImmunoReach RCN has tried to bridge the gap by aligning immunology-specific concepts and learning outcomes with the overarching concepts for life science education (46). At a professional level, the time devoted to teaching immunology greatly varies (47), even though, conceptual understanding of immunology is critical to succeed as a medical professional (48).

RECOMMENDATION #4: IMPLEMENT A CALL TO ACTION FOR A SYSTEM-LEVEL TRANSFORMATION AND INCREASED ACCESS TO IMMUNOLOGICAL CONTENT

The need for immune literacy for all individuals warrants the integration of immunological concepts starting at the K-12 level, building into introductory science classes in college and expanding to build expertise by late college for those going into careers where higher immune literacy is important. By incorporating immune literacy into K-12 science or health curriculum, those who do not pursue the route of a college degree would still have enough immune literacy to make more informed choices about their individual health and an understanding of the implications of those decisions on societal matters. For students who pursue college introductory science courses, both majors or non-majors, building on the foundation laid in K-12 will expand their understanding to a level that they are able to better distinguish misinformation and share a role in creating a more immune-literate society.

It is critical that we acknowledge the feed-forward cycles within the system. In educating the public, teachers at every level play a vital role, and their input in curriculum design is critically important. This includes educators in professional and graduate schools, undergraduate institutions, preservice teachers, and teachers in K-12 educational systems. Teachers may avoid teaching content they are not comfortable with, and therefore continuous teacher training and support is important. Teacher training can take the form of participation in a community of practice, short professional development opportunities, or more elaborate coursework, licensures, certifications, and accreditations. In addition, pedagogical, outreach, and science communication skills should be encouraged for immunology scientists in training, through formal training programs and didactic coursework. These measures cannot be successful unless we acknowledge the time limitations, low pay, and other stresses on teachers and professionals in training. Incentivizing the process and creating equitable opportunities for all is critical. Professional societies and institutional administrators can provide vital support in aligning their priorities and putting immunology education on par with immunological research.

CONCLUSIONS

Immune literacy requires continued public dialogue at every level—both within scientific and educational communities and among the general public. For this, a system-level change is required, one that starts with acknowledging the need for immune literacy and then improves by developing

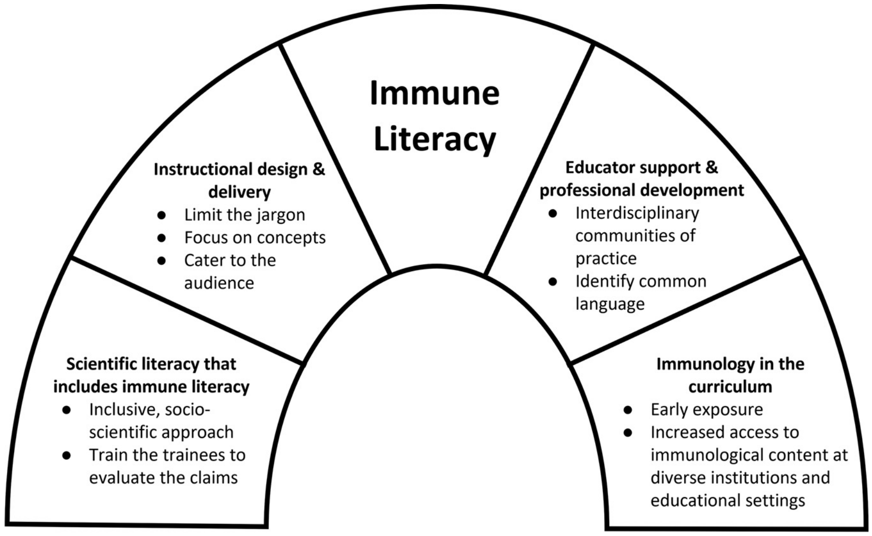

FIG 1. How to build immune literacy.

grassroot efforts to bring about this change according to the recommendations noted above (Fig. 1). The National Science Foundation-funded RCN, ImmunoReach, was established in response to this need and will continue to foster the movement of immunology into different educational settings, including undergraduate studies, K-12 education, and beyond. In this perspective, we request a call to action for a system-level change to foster immune literacy in classrooms, communities, and beyond.

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