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A multi-pronged approach to addressing curricular challenges in undergraduate immunology education

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Immunology is typically offered as a single-semester course in non-immunology-focused graduate programs and as a module within foundational sciences or microbiology courses in conventional allopathic medical education. Undergraduate courses in immunology are frequently stand-alone upper-level lecture courses without an accompanying laboratory, and often leave students overwhelmed by the complicated molecular cascades and cell subsets. This creates a barrier for immune literacy among biology students, and students at large, all of whom are nonetheless impacted by the workings of their immune system every day, and stand to benefit from understanding how it functions. We addressed this barrier with a multi-pronged approach of elective immunology courses, first-year seminars, a majors' survey course with a skills-based lab, advanced topical seminars, and an inquiry-based immunological research methods course. In this perspective article, we share our pedagogical practices to enhance immune literacy across all levels of a liberal arts and biology curriculum. Students can take one, several, or all of these courses during their undergraduate studies to build and bolster their understanding of immune systems and address the crucial need for increased scientific and immune literacy.

KEYWORDS

immunology education, undergraduate students, liberal arts, undergraduate research, immune literacy, active learning and teaching methodologies

Introduction

Public engagement in immunology shifted dramatically when the novel coronavirus SARS-CoV2 swept the globe in 2020. An editorial in Nature Reviews Immunology noted, "immunological jargon has become a staple of everyday life—members of the public freely discuss antibody tests, immunosuppressive drugs, and the relative merits of the various COVID vaccines" (Nature Reviews Immunology, 2021). Four years later, immunological discourse is once again in the headlines with increasing vaccine hesitancy in the U.S. (NPR, 2025) amid a multi-state measles outbreak (U.S. Centers for Disease Control and Prevention, 2025). It would appear that these days, everyone needs to be an immunologist (New York Times Opinion, 2023). It is particularly timely, then, to consider the landscape of immunology education for college students—a demographic that is largely considered to be one preparing to shape and lead science, public health policy, and society.

Immunology, when included in an undergraduate biology curriculum, is often a single course (Bruns et al., 2019, 2021; Pandey et al., 2022a), frequently offered without an accompanying laboratory. This "one and done," mostly theoretical, approach can be tantalizing,

giving students a glimpse into this fascinating, rapidly evolving, interdisciplinary biomedical field and sparking their interest to pursue it further through mentored research experiences and graduate studies. It can also leave students overwhelmed and frustrated by the sheer volume of new terms, acronyms, molecular cascades, and subsets of cells with finely nuanced functions (Pandey et al., 2022a) that do not lend themselves well to intuitive, "sticky" learning. These challenges are not specific to undergraduates; medical students often have similar experiences (Reynolds et al., 2022). Furthermore, the general public often recognizes the immune system as a helpful "germ fighter" and inflammation as a harmful phenomenon to be tackled with an abundance of anti-inflammatory drugs and supplements (Oronsky et al., 2022). Both views often suffer from a lack of nuance that is exacerbated by misinformation that floods social media and other networks (Allen et al., 2024), emphasizing the need for more immunology education at all levels.

Mixter et al. (2023) enumerate four fundamental challenges in immunology education—lack of attention to fundamental non-specialist immune literacy, the complexity of the subject matter, dearth of resources for professional development for educators, and design constraints of undergraduate biology curricula that serve a wide range of students. In this article, we discuss four types of undergraduate immunology courses we designed and taught at Macalester College between 2006 and 2025 (Table 1; Figure 1) that address one or more of these challenges.

Macalester is a selective undergraduate liberal arts institution in the U.S. Midwest with ~2000 students and a 10:1 faculty: student ratio. Alongside one or two major/s, all students complete graduation requirements in physical sciences, humanities, fine arts, social sciences, and global languages. Situated within the Biology Department of eight full-time faculty, including one immunologist[1], our immunology courses spanned the biology curriculum and provided a robust, effective, and enduring engagement with immunology for hundreds of undergraduate students across biology and neuroscience, and other majors. Our minimal prerequisites, multi-level, multi-course approach addresses several aspects of the challenges identified by Mixter et al., and provides a template for other educators to expand access to immunology for undergraduate students at all stages of their college career.

First-year seminars

We introduced first-year college students to immunology through courses without prerequisites that did not count toward any specific major. We used a novel "R" framework of immune functions—recognition, response, recruitment, resolution, regulation, repair, and remembering—that maintain tissue integrity in the context of changing internal and external environments and perturbations to introduce and emphasize conceptual understanding of immune responses (Supplementary material 1). Students practiced close reading, critical writing, informed conversation, compared and contrasted immunological content from peer-reviewed and journalistic sources, and reflected regularly on their learning to metacognitively (Wirth and Aziz, 2010) cement their immunology learning (Figure 1).

In "*Bodies on Fire*"—we studied post-infection sepsis, misdiagnosis of anti-NMDA receptor encephalitis as schizophrenia, global increase in food and chemical sensitivities, and ended with a meditation on how self may be constructed through health, information, connection, and memory[2]. Students mapped the immune system on life-size "immunological selfies" on butcher paper, read physician, patient, and scientist memoirs, and confronted the double-edgedness of protective and pathological inflammation. While some pursued further courses in cell biology and immunology, all of them appreciated the criticality of immunological understanding in the arenas of individual and public health.

"*Health in the Anthropocene*" linked inflammation, autoimmunity, and chronic infection to environmental pollution and human-accelerated climate change through heat stress, exposure to toxic pollutants, and chronic infections resulting from emerging, re-emerging, and shifting patterns of disease vectors. "*AIDS, malaria, influenza: Ancient pathogens in a brave new world*" integrated inflammatory responses, immunological memory, and geographic patterns of disease movement with the social, political, and environmental forcings of human activities. These courses asked students to connect a "cellular and molecular science" to planetary, societal, and ecological processes. Students were surprised, energized, and inspired by this connectivity and while some treated this first-year experience as a stepping stone toward a biomedically focused course of study, others took these understandings to majors in environmental studies, art, anthropology, literature, geography, and psychology.

Such courses can play a critical role in expanding undergraduate students' access to foundational immune literacy. While we offered these as first-year courses, they can be offered as non-major courses without prerequisites for all undergraduates. Such foundational courses bring nuance to the understanding of inflammation and immunity, and help students connect immunology learning to personal experiences, global events, and understandings of systems-level phenomena, including climate change. This throughline to criticality, relevance, and timeliness makes the content feel less distant and arcane and more essential to many things that students care deeply about while boosting immune literacy across the board, regardless of the students' intended majors.

Upper-level immunology survey course

We offered an upper-level immunology course with a laboratory almost every academic year, available to any students who completed the required previous coursework in chemistry, cell biology, and genetics. While the content emphasized innate and adaptive mammalian immune systems, we included discussions of bacteria, slime mold, ants, lampreys, African lungfish, plants, and algae to remind students of the evolutionary trajectory of host defense. We structured the class around the "R" framework

1 These courses were offered by a single instructor (DC: 2006–2021; ET: 2021–2025) supported by undergraduate teaching assistants.

2 Fatal Sequence (Kevin Tracey), Brain on Fire (Susannah Cahalan), Epidemic of Absence (Moises Velasquez-Manoff), and Faraway Nearby (Rebecca Solnit).

TABLE 1 Summary of the discussed immunology-themed courses, detailing course model, target student audience, prerequisites, typical enrollment, weekly time commitment, sample learning outcomes, and student reflections.

Course model	Course name	Primary audience	Prerequisites	Typical enrollment & weekly hours	Sample learning outcomes	Sample student evaluations (edited for clarity and length)
First-year seminar	Bodies on Fire; Health in the Anthropocene; AIDS, malaria, influenza: Ancient pathogens in a brave new world	First-year students (majors undeclared)	None	16 students 3 h/week for 15 weeks	Students from diverse backgrounds and interests will apply immunological ideas in systems thinking and as metaphors for change and resilience.	"…it made science and the immune system finally accessible and digestible for me, especially conceptually, since we were learning and exploring it through a variety of media…I truly think that's how I got to a point where I could imagine myself as a scientist. I still think about that course today and wrote about it for my PhD applications as the reason I got into immunology"
Upper level course	Immunology	Upper-level biology, biochemistry, neuroscience majors	Genetics; Cell Biology; General Chemistry	16–20 students 3 h/week + 3 h lab/ week for 15 weeks	Deep conceptual understanding of the principles of immunity as a homeostatic process. Apply immunological knowledge through data analysis and experiments and develop an immunology technique toolkit.	"…this class gave me a lot of passion for continuing the study of immunology!" "…I've learned so many things that I could use in future research settings, and this lab set me up for internship and grad school applications…" "I liked how the lab content built on itself throughout the semester and we got chances to repeat and learn from earlier experiments"
Advanced topical seminar	Cancer Immunology; Seminar in Immunotherapy; Neuroimmunology	Upper-level biology, biochemistry, neuroscience majors	Genetics; Cell Biology; General Chemistry	16–20 students 3 h/week for 15 weeks	Apply knowledge through data analysis, deductive reasoning, and experimental thinking in writing and discussions. Relate concepts to "real-world" applications and enhance the ability to evaluate ethical implications of research.	"…this was a great format for learning various diseases and how [to] use immunotherapy to treat them.…I really enjoyed our final projects as I feel like I got a true sense of the topic I was studying in a much further in-depth perspective than I could have gotten in class and I am excited to share with the class.… I liked class time to work on figuring out the figures since they were challenging but I feel like I grew a lot as a student. I really liked book club!"
Inquiry-based research methods class	Research in Immunology	All majors and level students interested in research and immunology	Genetics; Cell Biology; General Chemistry	6–10 students 3 h/week + 3 h lab/ week for 15 weeks	Appreciate science as a continual process of investigation and interpretation, with scientific knowledge progressing through hypothesis testing using evidence and logical reasoning. Collaborate with peers in class and lab, recognizing that science is a human endeavor improved by working with individuals from diverse backgrounds and expertise.	"Reading papers and answering the reading response questions helped me learn. I have a way to guide myself when I tackle a scientific paper. This class has given me the tools to read a figure in combination with other figures and what questions they answer, instead of reading the paper word for word." "Lab was absolutely fun and engaging and I learned so much…. a major part of facilitating my learning and the idea of "see one, do one, teach one" really worked well with the lab content and protocols."

Courses span first-year seminars to advanced seminars and research-based classes, highlighting the multipronged approach to addressing curricular limitations in all levels of undergraduate immunology education.

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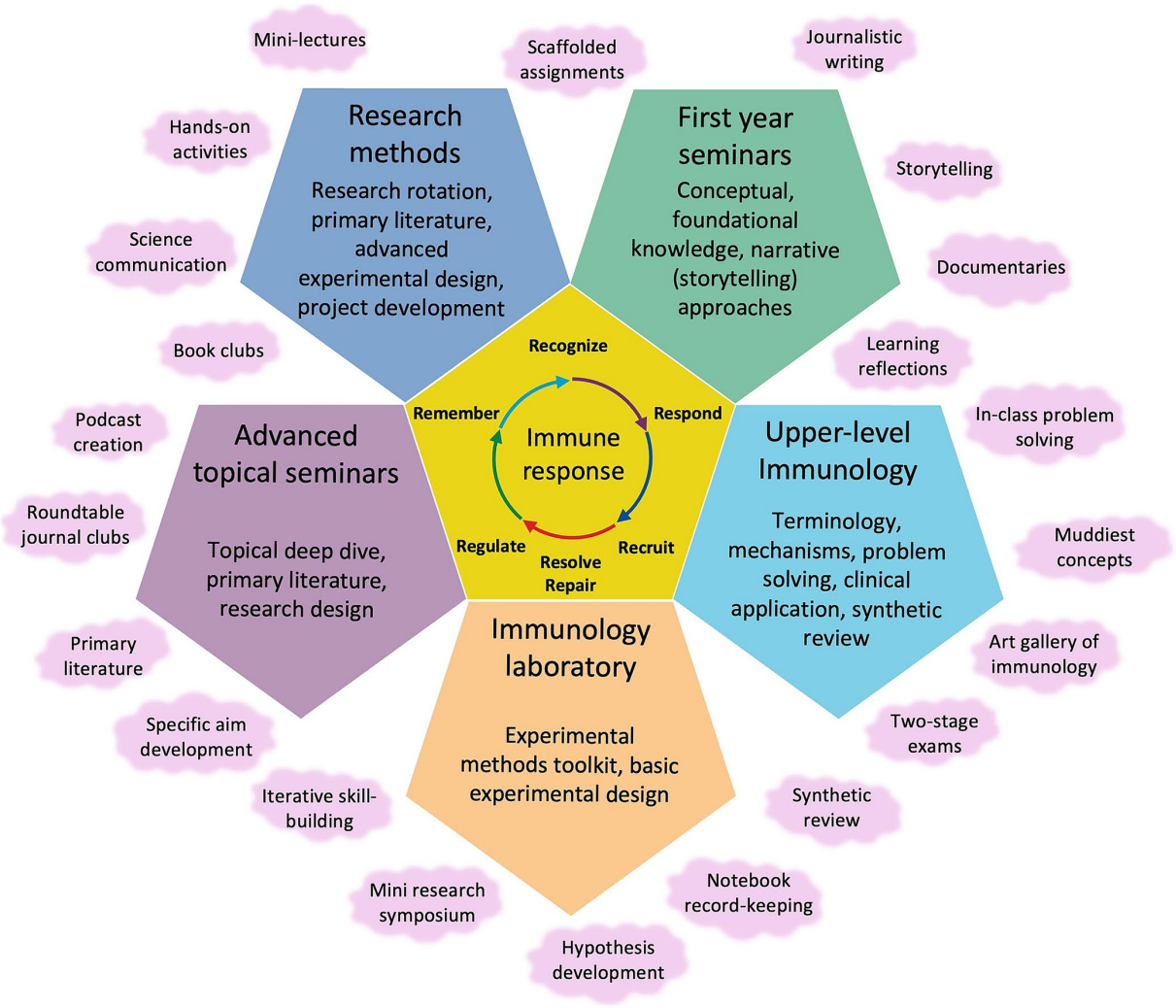

FIGURE 1
Framework for addressing curricular challenges in undergraduate immunology education in course design. A diagram of courses developed to enhance undergraduate immunology education with unique instructional foci highlighted. Surrounding the central diagram are representative assignments and activities that integrate cellular and molecular understanding of immunology with broader considerations of personal and public health and ecological change. Together, these elements we have employed across various iterations of our courses promote learning that connects foundational immunology knowledge at all levels of the curriculum to real-world applications and broadens accessibility of immunology education in an undergraduate curriculum. Throughout all the courses we employ the "R" framework in developing a conceptual understanding of immunity of any organism where Recognize—detection of danger of change via non-specific or specific receptors; Respond—activation of immediate immune responses; Recruit—triggering of signaling cascades to mobilize and coordinate immune players; Resolve and repair—resolution of inflammation and return to homeostasis; Regulate—balancing immune response activation and termination to avoid overreaction and/or autoimmunity; Remember—adapting future immune responses for long-term defenses. See Supplementary material 1 for more details and example topics.

(Supplementary material 1) and challenged students to animate the concepts with specific terminology, mechanistic analyses, and clinical applications. Students supplemented lectures and textbook reading with primary and popular literature. We used learning-centered assessments emphasizing comprehension, a "data-first" approach to analyzing primary literature through journal clubs (Supplementary material 2), independent group lab projects, and assignments that connected immunology to creative expression and community engagement.

We used two-stage assessments with individual problem-solving followed by a collaborative, small-group revision, to encourage cooperative learning. We also used oral final exams to assess students' holistic understanding in the context of a broad, big-picture question on the function of the immune system in health and disease. To minimize anxiety associated with an unfamiliar approach, the students were provided the broad questions ahead of time, followed by more in-depth and clarifying real-time questions stemming from their opening answer in an individual conversation with the instructor. In both cases, students had the opportunity to clarify their understanding during the assessment, thus advancing their overall learning.

Moving away from the "banking model of education" (Freire, 1970), where the focus is on "depositing" information and understanding into students, we encouraged students to critically engage in transforming their understanding into social goods and activities. Students designed board games and interactive museum exhibits, and wrote children's books. They volunteered with local and

national community and advocacy organizations, including the Immune Deficiency Foundation. They made art (Chatterjea, 2020), podcasts, and lesson plans for a girl-focused STEM middle school in Saint Paul. Demonstrating their understanding of complex immune topics well enough to express them in myriad and sometimes unconventional ways challenged and rewarded students powerfully. Throughout iterations of this course, and indeed through almost all iterations of the other courses we describe in this perspective, we asked students to reflect regularly on their learning through short weekly written assignments—what struck them most, what was clear, what was confusing, what they were curious to learn, how immunology learning connected to other parts of their lives etc. This meta-cognitive intervention (Wirth and Aziz, 2010) was key to helping students take ownership of their learning and helped us reframe and redirect our instruction in real-time to make it more personalized for individual students and more effective overall.

The skills-based laboratory portion of the course allowed hands-on exploration, mastery of skills, project development, and hypothesis testing. We structured the lab to support iterative skill-building of basic immunology techniques, including *in vitro* cell stimulation, ELISA, and flow cytometry, allowing the students to use their knowledge to design and conduct a set of simple experiments to test the immunomodulatory potential of dietary supplements in teams culminating in a mini-research symposium of group oral presentation to share their findings. Throughout the course, we emphasized thorough experimental record-keeping in their laboratory notebooks, allowing students to develop skills for future careers in industry and academic settings.

This course, counted as an upper-level class toward biology and neuroscience majors and biochemistry emphasis across its many iterations, met the growing need for undergraduate students to engage deeply with core immunology principles, experimental approaches, and real-world applications for a variety of post-graduate biomedical training including immunology PhDs, medical school, and nursing school.

Advanced topical seminars in immunology

While the inquiry-based, skills-focused course lab was a strong and valued component of our immunology survey course and the biology curriculum overall, many students did not have space in their major plans for the time-intensive immunology survey with lab. For these students, and also for students who wished to build on that survey through deeper topical explorations, we offered elective primary literature-based immunology seminar courses on topics ranging from Cancer Immunology and Immunotherapy to Neuroimmunology, all requiring chemistry, genetics, and cell biology coursework as preparation, but open to all students regardless of their major (Table 1).

Because of the mix of immunology expertise in these courses, it took intentional effort (mini-lectures and in-class problem-solving) to bring everyone to optimal learning and participation. Students who had not taken immunology frequently brought other expertise—neuroscience, biochemistry, microbiology—that enriched the learning experience for all students. We used scaffolded assignments to help students become careful and critical readers of research papers—to effectively parse data figures, find and use sources to better understand methods used (critical in a course with no laboratory), place the study in the context of what understandings came before and after, and identify both the significance of any given finding and the inevitable blind spots of any study design. Students took turns presenting figures from a paper in roundtable-style discussions and completed guided pre-class writing assignments (Supplementary material 2). For their culminating project, we asked them to write a synthetic review of an immunological topic of their choice or develop specific aims for a grant proposal in the area. For all students, these activities reinforced skills they had begun to acquire and resulted in deeper learning and connective, generative immunological thinking.

In these literature-focused classes, we also designed additional in-class activities and assignments to guide students towards a deeper societal application of their knowledge. Immunotherapy students participated in a book club discussion of a non-fiction book (Brain on Fire; Susannah Cahalan) about the immune system function and dysfunction, which also led to considerations of ethics in research and medical practice in the US. The Neuroimmunology seminar emphasized public communication of science and mental health awareness on campus and in the community through final projects that included podcasts, campus posters, and zines/leaflets for local community centers.

These courses counted as advanced electives for the Biology major and concentrations in neuroscience and biochemistry, thus supporting a broad range of curricular needs at our institution while providing access to a variety of immunology topics. Seminars on these and numerous other possible topics can effectively build sophisticated immunological understanding, provide a pathway for students to participate in the ongoing scientific "conversation" on the topic via the primary literature, and whet their appetites for further study in the field.

Inquiry-based immunological research methods class

Learning immunological concepts and understanding how they were uncovered through research is essential, but developing the skills to do research requires a deeper level of engagement. These "research muscles" can only be built and strengthened through consistent practice. Yet, it is difficult to capture the dynamic, research-driven nature of immunology in a typical undergraduate course. Course-based undergraduate research experiences (CUREs) have aimed to address this gap throughout the college science curriculum (Soto et al., 2025). In practice, traditional course labs are converted to CUREs, but integration between lab and lecture, and insufficient time for students to engage with previous work in the field to inform authentic inquiry, remain challenging.

We addressed this challenge through Research in Immunology, a course focused on experimental design and mastery of methods structured as a mentored, team-based rotation in our research lab. Up to ten students, typically upper-class biology or neuroscience majors, and younger students curious about research (Table 1) collaborated with us and each other to identify novel questions within the scope of our research program. Students read, critiqued, and applied current research to develop hypothesis-driven projects and dissected published studies to refine their questions, while learning and optimizing methods required to pursue their inquiries.

This class was highly interactive and used many active learning approaches. "Journal club" discussions included roundtable discussions, concept mapping, and "mini posters" of figures redrawn and presented on whiteboards. In "Data club" students presented work in progress for peer and instructor feedback. To prepare for the journal club discussions, student facilitators took turns to prepare an introductory presentation contextualizing the studies, and other students completed reading responses to questions thoughtfully designed to guide their reading and understanding of scientific articles (Supplementary material 2); all students completed weekly learning reflections. For the laboratory portion, students learned fundamental techniques that they refined and mastered through repetition. As the semester progressed, students frequently met in addition to scheduled lab times to complete their group-based independent research projects. Each group produced a final summary of their work, either a short scientific paper or a poster presentation, detailing their experimental rationale, design, methods, findings, and significance presented at the final class meeting and opening the floor to discussion by the whole class (Figure 1). Some students subsequently joined our research team, completed honors or capstone projects, and contributed to 40 unique undergraduate authorships in 14 peer-reviewed publications. Nearly a dozen alums went on to enroll in immunology or related PhD programs, with several now producing and applying immunological knowledge as principal investigators and industry scientists.

Discussion

With nearly 400 Cluster of Differentiation (CD) designations, 40 interleukins and 80 functional subsets of cells and counting (Catalan-Dibene et al., 2018; Fang et al., 2018), immunology classes can feel especially out of reach for those without previous cell biology and genetics experience. The novel "R" framework we have employed in our classes (Supplementary material 1) minimizes the barriers to understanding as it emphasizes an intuitive, conceptual approach to immunology and invites students to use immune responses as maps and metaphors to understand change and resilience in any complex system. In this perspective we have shared a strategy of offering courses at all levels of the curriculum, with no to low barriers to entry, appealing to everyone from first-year/non-majors to students actively seeking to develop research and experimental design skills in preparation for employment and/or graduate studies in the field, ultimately broadening access to immunology in the classroom and beyond (Table 1).

Our courses invited students to connect foundational learning in immunology with social, political, and environmental phenomena, and challenged them to engage with the material through close reading, reflective and analytical writing, experimental design, professional and public communication, and art to support broad non-specialist immune literacy and lay the groundwork for future advanced immunological inquiry. Notably, we used similar strategies, assignments, and activities, with modifications for curricular level, across several of our courses (Figure 1), thus streamlining course design and ideation. The undergraduate and medical immunology educators community has been actively sharing materials (Garrison and Gubbels Bupp, 2019; Rawlings, 2019; Riestra et al., 2019; Stranford et al., 2020; Porter et al., 2021; Pandey et al., 2022b), expanding the resources available to both experienced and newer educators of students interested in biomedical sciences. This growing community of practice fosters innovation and inclusivity in immunology education and helps ensure wider access to the exciting field of immunology.

While immunologists at larger research universities have successfully deployed undergraduate majors in immunology (Bruns et al., 2019; Justement and Bruns, 2020), that approach does not easily fit a small liberal arts college (SLAC) such as Macalester which emphasizes a connective and broad education. Instead, we designed and offered an array of immunology courses that invited students across many majors (biology, biochemistry, anthropology, psychology, geography to name a few) as long as they had the necessary pre-requisite coursework while first-year students were invited to take topical immunology courses that did not require any prior coursework. Over nearly 20 years, our inclusive, multi-level approach introduced several hundred students to immunology, inspired over 150 students to pursue multi-year projects in our research laboratory, produced 14 (and counting) peer-reviewed publications with 40 + unique student co-authors, and led to over a dozen students joining prestigious immunology PhD programs and launching successful careers in academia and industry after completion of their doctoral and post-doctoral studies. Anderson et al. found that timing of educational and mentored exposures to immunology and immunology research led to students pursuing further studies in immunology (Anderson et al., 2021); our experience aligns with this observation. In addition, the positionality of our work within the liberal arts expanded the impact of our teaching into broader immune literacy across a range of professions and expertise beyond biomedical research.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding authors.

Author contributions

ET: Writing – original draft, Writing – review & editing. DC: Writing – original draft, Writing – review & editing.

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immunologist, educator, and founding director of Macalester College's Serie Center for Scholarship and Teaching.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The author(s) declare that no Gen AI was used in the creation of this manuscript.

Publisher's note

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/feduc.2025.1640703/full#supplementary-material

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