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Strategies for navigating primary scientific literature in undergraduate immunology courses

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The impact of immunology on our daily lives is growing every year. From vaccines to immunotherapies, it's essential for our healthcare professionals (present and future) and the general public as patients or caregivers to be literate in immunology. One way to foster immune literacy in this rapidly advancing field is through Primary Scientific Literature (PSL). There are unique challenges with integrating PSL into immunology courses. First, the laboratory techniques used are often new and not things students have tried before or may have access to, such as flow cytometry. Second, the tools used in this literature can be confusing. For example, antibodies are often used as both part of the research method and as the research subject. Third, immunology literature is especially heavy in acronyms, jargon and abbreviations. In this manuscript, four instructors gathered to discuss the strategies that they have used in their classrooms to utilize PSL in immunology (PSL-I) and scaffold various activities around it. These teaching methods vary from highlighting immunology-specific techniques, interpreting figures, alignment with the 5E instructional model to guide an inquiry, jigsaw format learning, to in-depth journal-club style analysis. Finally, this paper discusses reflections from our experiences teaching PSL-I. We know that there are misconceptions about immunology and health in general. If we teach PSL and how to interpret it, we hope to prepare our students not just for their chosen field, but also to think critically and discern facts from fiction in society.

KEYWORDS

figures, jigsaw, journal club, ImmunoSkills, scaffolding, active learning, competencies, 5E instructional model

1 Introduction

Medical schools cite "development of habits of inquiry and innovation" (Irby et al., 2011) and "competency-based medical education" (Pien et al., 2022) as top priorities for training[1]. However, on average, medical students and practitioners alike only spend about 10.8 min looking for information (Brennan et al., 2014) and doctors tend to select textbooks and conversations with colleagues before they sought electronic sources (Davies, 2007). This is particularly problematic in the field of immunology, where the publications,

1 AAMC (2025).

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especially those featuring large shifts in knowledge, are growing exponentially (Yao et al., 2023). Therefore, it is crucial that we train our future medical professionals to interpret and understand Primary Scientific Literature (PSL) so they can use this growing resource in their training and future medical practice.

It is also important for the general public to be literate in immunology as they are increasingly exposed to it in their daily lives, from vaccines to potential epidemics, such as bird flu, and new medications. As immunological research grows, so do available immunotherapies. As of December 2024, there were 225 monoclonal antibodies approved or under review in the EU or US, about 10% of which have been approved within the past 2 years[2]. The global market for antibody drugs was $234.37 billion in 2023 with a projection for rapid growth[3]. With antibody drugs available for a rapidly increasing number of conditions, the number of patients receiving these therapies are also increasing. Patients and their caregivers must understand how these medications and other immunotherapies work to make informed decisions about their options. Training to read PSL in Immunology (PLS-I) to gain scientific and immune literacy skills can help students navigate these important topics that lead to a healthier life.

Over 70 different approaches have been used by instructors to teach PSL in STEM disciplines (Goudsouzian and Hsu, 2023; Hoskins et al., 2011; Round and Campbell, 2013; Sato et al., 2014; Clark et al., 2009; Flaspohler et al., 2007). Immunology courses can, however, create challenges for adapting these activities. The methods described in immunological studies, for example, Neutrophil Extracellular Trap assays, or technologies, such as confocal microscopy, ELISAs, and most notably, flow cytometry, are often unique. While prominent in the field, flow cytometry can be complicated to teach for multiple reasons: (1) Students often don't have access to a flow cytometer because it is cost-prohibitive (Pandey et al., 2024). As a result, they won't actually see or use the machine that created the data. Therefore, faculty must elicit student understanding of the data from the theoretical use of this new technology. (2) Flow cytometry data is presented in images and figures that other scientists do not use and may not readily recognize, so students have likely not seen it before. Since journal articles are written to disseminate information to professional immunologists with an extensive background and aim to convey the information as succinctly as possible, these figures may not be explained in detail or at a level understandable to undergraduates. (3) Flow cytometry has multiple uses, including simple monitoring, multichannel use for quantification of multiple cell populations, and cell sorting, which demands students to comprehend the context of its usage besides just knowing how it works. In fact, students in a research-based master's program rated "techniques" and "experimental data" as the two most challenging parts of understanding primary literature (Lie et al., 2016).

In addition, the use of antibodies in research is a new concept for most of our students. Students learn about the role of antibodies in the immune response but have a difficult time grasping how antibodies can be developed in a laboratory for diagnosis, monitoring of diseases and even as therapies. Essentially, antibodies can be both the research subject and a research method.

Finally, the field of immunology is notorious for rampant jargon and abbreviations in the literature. The cell signaling molecules and immune cell receptors are denoted by a combination of letters and numbers that students haven't seen or used before. In 2020, a news article in Nature Index claimed that "science is getting harder to read." They cited the number of acronyms, long sentences, and impenetrable jargon[4]. Here is a title of a paper from the Journal of Immunology that illustrates this point: "Cutting edge: IL-27 induces the transcription factor c-Maf, cytokine IL-21, and the costimulatory receptor ICOS that coordinately act together to promote differentiation of IL-10-producing Tr1 cells." Conversely, while the field is increasingly challenging to enter, demand for immunologists is growing faster than the average occupation[5]. It is increasingly important that present and future immunologists and other medical professionals can break through the jargon and understand PSL-I.

2 Pedagogical principles underlying PSL integration in immunology courses

Reading PSL can be an effective tool to prepare our students, position them for success in professional and graduate schools, and empower them to make informed decisions about their own health and that of their friends and family. Additionally, there are significant pedagogical advantages to integrating a PSL-I-based approach into practice, as discussed below:

i) ***Staying up to date with rapidly evolving discipline***. Immunology as a discipline is at the forefront of technical and scientific discoveries. There is a significant lag time before discoveries make it into textbooks. In fact, comparing outdated and updated textbooks has been suggested as one of the strategies to introduce students to PSL (Segarra and Tanner, 2015). PSL can serve as a resource to help educators and their students stay current, and directly engage with these discoveries.
ii) ***Provide context for lab techniques***. Immunology textbooks often include a chapter on an immunologists' toolbox that outlines important experimental techniques, which can be adopted in a cookbook-style format in an immunology laboratory. However, PSL-I helps provide context for these techniques. It helps students gather a more complete picture of how these techniques can be applied to a research problem and/or a real-life clinical scenario. Several previous studies have reported the integration of PSL-I with laboratory experimentation (Morán et al., 2006; Ramos Goyette and Deluca, 2007; Marbach-Ad et al., 2007; Gunn et al., 2013; Dolence, 2021), and a few have reported strategies for directly engaging students with PSL-I (Anderson et al., 2020; Morgan, 2022).

2 Antibody Society (2025).
3 Global Newswire (2025).
4 Nature Index (2025).
5 University of Utah Health Academic Medical Center (2025).

iii) ***Set the stage for argumentation and critical thinking***. Deciphering and critically analyzing PSL-I can be important for our students, and by proxy, to their friends and families, to make informed, evidence-based decisions. It is a skill that, when applied effectively, can serve to prevent the rapid spread of misinformation in our society. Engaging with PSL-I can allow for scientific discourse in a classroom setting. Several studies have systematically assessed the benefits of integrating PSL in classrooms, showing improved self-reported student learning gains in biology (Chatzikyriakidou et al., 2022), enhanced critical thinking skills (Sato et al., 2014), increased ability and confidence to read and analyze scientific literature and understand complex content (Hoskins et al., 2007).

iv) ***Alignment with the Vision and Change and ImmunoSkills Guide***: The *Vision and Change* report[6] and the ImmunoSkills guide (Pandey et al., 2024) described core competencies for undergraduate biology students, and PSL-I addresses several of them at once. Identifying the learning outcomes, and alignment of activities with those is a critical step in adopting backward-design to curriculum plan (Wiggins and Mctighe, 2005; Fink, 2013), and can help instructors assess student learning and effectiveness of their pedagogical practice.

v) ***Transferable skills development in students:*** These skills and competencies are not only critical for students to master but transcend disciplinary boundaries and can be used to decipher PSL in any discipline. They can help facilitate student transition into doctoral programs (Kozeracki et al., 2006). Students who engaged with PSL in classrooms expressed decreased frustration with interpreting data in figures (Round and Campbell, 2013), and increased self-efficacy in analyzing data from research papers, evaluating authors' conclusions, designing experiments, and interpretation of controls (Abdullah et al., 2015). They also showed enhanced oral and written communication skills and collaboration among peers (Mulnix, 2003).

vi) ***A tool to integrate active learning:*** Compared to traditional lecturing, active learning has been shown to increase student performance in STEM disciplines (Freeman et al., 2014), and by using strategies such as jigsaw, journal-clubs, or guided inquiry, PSL discussion serves as one of the potent ways to bring active learning into the classroom. This can shift the classroom to be student-centered, where students are not only passively listening to the disciplinary content, but actively engaging with how science is done and reported.

vii) ***Foster science identity and belonging***: PSL can be a great way to introduce students to the process of science and people who do science, which can help with their scientific identity and belonging. Studies on the C.R.E.A.T.E. approach to teaching primary literature, for example, have reported a shift in students' epistemological beliefs including their self-assessed understanding of the nature of science, scientists as people, and their insights into the process of science and learning (Hoskins et al., 2011; Stevens and Hoskins, 2014; Gottesman and Hoskins, 2013).

6 AAAS (2011).

3 Learning environment

While there have been several reports of curricula or activities that integrated PSL-I (Morán et al., 2006; Ramos Goyette and Deluca, 2007; Marbach-Ad et al., 2007; Gunn et al., 2013; Dolence, 2021; Anderson et al., 2020; Morgan, 2022), a broader perspective on alignment with immunology-specific skills and competencies or how they overcome challenges unique to immunology, is missing. The following narratives by immunology educators describe four methods of supporting PSL-I for science majors in upper-division Immunology courses within 4-year programs at these institutions. These courses use PSL-I to address the key competencies from the ImmunoSkills Guide, as shown in Table 1 and Supplementary material, Table S1.

3.1 Narrative 1: figure interpretation and technology of the week

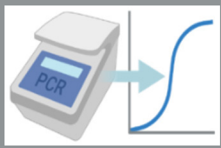
At a 4 year primarily undergraduate institution (PUI) where I teach pre-health students data analysis is required both in our biology major learning objectives, and in my 300-level immunology course. Since I began prioritizing figure interpretation to foster critical thinking, I have noticed that my students excel on the Critical Analysis and Reasoning Skills portion of the MCAT, notoriously the most difficult section in which to improve your score.

To help students parse out these complex figures, I developed the Data Interpretation Worksheet (Supplementary material 2), a one-page guide that breaks down complex figures into simple questions. This provides students with entry points to otherwise overwhelming figures and helps learners articulate specific areas that need help understanding. We interpret practice figures as a class at the end of nearly every chapter. These practice figures allow students to apply the concepts they have learned in that chapter to current research. The first few figures take a lot of time (15–20 min each), but the students improve quickly as the semester progresses. By the end, most students don't even need to pull out the worksheet and can analyze figures without guidance.

I also support their data interpretation skills by having an explicit "technology of the week." At a small liberal arts college, we don't have access to most of the equipment used to generate these figures. Before interpreting the figures, we discuss the technology in class, including what it is used to analyze, its immunological underpinnings, and its strengths and weaknesses. Students fill out a 1-page worksheet summarizing their understanding of the technology, and then apply this understanding by interpreting a figure generated by the technology discussed. They can use their technology of the week worksheets on the exam, because in most instances you would be able to look up details about a method while reading a scientific paper (Supplementary material 2).

I assess data interpretation on each of my exams. This shows me how students' skills are progressing and helps place value on the need to adapt and interpret in this field. Low-stakes practice in class helps them perform well on these high-stakes exams. Furthermore, it provides an assessment avenue that helps students who struggle with memorization but can apply the material.

TABLE 1 Four distinct ways to integrate primary scientific literature in undergraduate immunology classrooms and their alignment with the ImmunoSkills guide.

Core competency	Figure interpretation/ technology of the week (S2) 	Journal-club (S3) 	Jigsaw (S4) 	5E (S5) 
Process of science	✓	✓	✓	✓
Communication and collaboration		✓	✓	
Metacognition	✓		✓	✓
Science and society				✓
Quantitative reasoning	✓	✓	✓	✓
Explain laboratory methodology	✓	✓	✓	✓

I emphasize the figure interpretation aspect of reading scientific papers because that is how I read papers as a scientist. I flip to the figures, refer to the background and methods for aspects (or acronyms) I don't understand, make my own interpretations and then check the discussion to see if the authors agree with me. I'm hoping to impart these hard-learned skills to my students earlier on in their careers so they can save time and get more out of scientific papers than I did at their stage.

Overall, when I ask former students how they are doing in graduate school, they often say other students don't have "common sense" or "know how to think." Critical thinking is a gift we can give our students that will serve them well throughout many aspects of their lives.

3.2 Narrative 2: journal club style

In my university's traditional undergraduate division, this PSL-I journal-club activity was implemented during an in-person, 400-level elective immunology course for primarily biology majors in our Science Department. I assign students a paper to read and have them complete a detailed written assignment followed by journal club-style in-class discussions I call "Tutorials" that delve intensively into each journal article to learn the techniques used, what the data show, and how the authors interpret the findings.

To address the challenges of teaching PSL-I to undergraduates, I strive to break down and teach the background information needed to understand each article. This includes introducing all the terms they will encounter, materials used, and techniques utilized. For example, if a paper uses multiple bacteria species, I will compare the different species. If they use cytokines, I will explain their origin and what they are thought to do in the body. I also help them distinguish between antibodies used for research and detection. Students will then be able to approach each article with at least a rudimentary background.

To address the challenge of reading these detailed papers, students are taught the anatomy of a research article and become familiar with how scientists communicate their work. I teach students that the article's overall question the authors are asking, and main conclusions are typically found in the abstract and introduction section of the paper. Students learn to interpret and explain the Figures and Tables to address what the experiments are showing. In the written Tutorial Homework (example in Supplementary material 3), I ask students to identify a) the question the authors are trying to answer (i.e. the hole in knowledge), b) what they did to find the answer, including basic methods (e.g., comparing protein expression by Western blot), and c) what was the answer [answer the question from (a)] for most figures in the paper. The goal is that students can identify the patterns of PSL so they can determine the important question the paper addresses in the field and the authors' findings and impact. An important aspect of Tutorial Homework is that these assignments are scaffolded to be worth fewer points at the beginning of the course, after which I give considerable feedback. The point values increase as the semester progresses and students get used to the process.

After students have completed and turned in the written Tutorial Homework, we hold a whole-class roundtable "Tutorial Discussion." I arrange the chairs in a circle and students take turns answering each question from the assignment. If a student has an incomplete understanding, we discuss the possible answers. They are not penalized for incorrect answers when grading their participation, but I am looking for evidence that they have read the article and spent time trying to interpret it as instructed. This discussion is not just a formality, but a valuable opportunity for students to share their thoughts and learn from each other.

I've heard informal feedback from students that the Tutorial Assessments were difficult, but they got easier throughout the semester. In end-of-semester optional and anonymous feedback, I asked these questions: "The papers we covered during Tutorial Assignments were appropriately challenging but readable" and "I gained a better understanding of how to read, analyze and discuss scientific literature in this course" with a 5-point Likert scale from strongly disagree to strongly agree. Results over two semesters showed 83% of students ($N = 13$) agreed or strongly agreed with both questions.

3.3 Narrative 3: jigsaw format

This primary literature jigsaw is implemented in a 400-level elective Immunology course at a small liberal arts PUI. The majority of the biology and biochemistry students who take this course pursue healthcare careers. This discussion-based seminar is taught as a seminar-style course in the major, where students prepare for class by reading the text and answering discussion questions.

There are various methods to help students improve their ability to read and understand scientific research articles. I choose articles that relate to the course content and have broad interest. For example, early in the semester, when studying cells of the innate immune system, I chose a paper describing Neutrophil Extracellular Traps (NETs; Brinkmann et al., 2004). This paper was relatively brief, had easy-to-understand techniques, and presented a finding that was surprising to students. Once I have chosen an article, I utilize a cooperative jigsaw methodology (Finelli et al., 2005) to help students dissect the paper. Prior to class, the students read the article and identify 10 words they need to look up the definitions for, and then in class, I assign groups of three to five students one section or figure(s) of the paper. The students then dive more deeply into the terminology and technique from their piece of the jigsaw. Once the groups are comfortable with their portion, I scramble them, ensuring each new group has one person from each paper section. At this point of the jigsaw activity, they put the puzzle together by teaching each other what they learned from their portion of the paper, and they put the sections into the whole context. Finally, the class comes together and reports to the class to make sure there is a similar level of understanding.

I assess student learning via scientific communication. Upon completing the jigsaw activity and resulting discussion, students' summative assessment includes presenting the paper orally or writing a journal article summary, incorporating what they have learned throughout the PSL-I exercise. The formative (in-class discussions) and summative (article summary) PSL-I activities are approximately 30% of the final grade. One of the difficulties with incorporating journal articles is the amount of class time required. This jigsaw assignment can take one to two class periods to complete, depending on the complexity of the paper. However, PSL can serve to reinforce current and previous class material as well as introduce new material. I incorporate the paper into parts of multiple class sessions so there is time for students to think about and synthesize the information.

The jigsaw activity presented impacts student learning gains and metacognition as measured by formative and summative assessments. The evaluations include discussions, the Student Assessed Learning Gains (SALG) survey (Seymour et al., 2000), and a written summary of the journal article. Formative assessments included competencies such as critical thinking, the process of science, and scientific communication. These competencies were assessed with the SALG survey as a pre-post survey using Likert scale questions. This survey also includes open-response questions that ask the students to reflect on what they learned, which can be used to evaluate metacognition. Finally, the summative assessment, as outlined in Supplementary material 4, assesses student learning gains via their ability to explain the findings and put them into context within the field, demonstrating the student's understanding of the subject matter, their ability to synthesize concepts and applications and to communicate complex scientific information.

3.4 Narrative 4: 5E approach to read and understand PSL-I

This activity has been implemented at a PUI, in an asynchronous, 8-week long, upper-level immunology course designed for undergraduate biology majors. In this writing-intensive course, 50% of the grade comes from a formal written project, i.e., a review article on a topic of students' choice, that they take through multiple drafts and peer review before submitting a final paper. However, over the years, it has become apparent that writing a review presents a steep learning curve as students face a litany of challenges. During informal conversations, one student described the PSL-I as having a "snow blinding effect" due to all the immunology associated jargon, acronyms and graphical representations unique to immunology. The activity described here (Supplementary materials 5) was developed and implemented to address some of the challenges described above, to help reduce the learning curve and give students enough exposure and practice with reading and understanding PSL-I, so they could write their own review article.

This approach used the 5E framework (Tanner, 2010) to design a set of questions (guided inquiry) from one research article (Xu et al., 2021), and these questions were released in phases over weeks 1–7. The design of questions and the weekly rhythm followed a 5E template: Week 1; **E**ngage with big picture questions and societal relevance of the research topic addressed in the paper, Week 2-6; **E**xplore and **E**xplain—the figures, techniques and terminology, using 1–2 figures from the paper at a time, Week 7; **E**laborate on the new learning to propose future research directions and experimentation, Week 7; **E**valuate your knowledge and learning using reflection based questions (metacognition). Week 8 was left free of this activity to allow students to apply the learning to their own review article and submit a final version.

Weeks 2–6 used a consistent format of questions focused on 1–2 figures from the paper per week so that students could practice graphical interpretation, 1–2 techniques and a few new terms in context of those figures. To expose students to immunological techniques like ELISA and flow cytometry, in this online, asynchronous offering of the course, Labster© (Somerville, MA, USA) simulations were used. The assessment for this activity was formative, as in the instructor provided feedback for each incorrect answer on the weekly submissions. The grade was based on a three-point scale: 0 = not turned in, 0.5 = partially completed worksheet, 1 = fully completed worksheet. Points were typically not deducted for an incorrect answer, but feedback was provided and misconceptions were addressed, so students can learn, integrate feedback into the future work, and continue to build on a strong conceptual foundation.

In the beginning, students struggled with identifying the relevant techniques associated with a figure. However, with the repetition built into this activity, this struggle diminished as the semester progressed. Anecdotal student reports noted that they started out the activity with apprehensions and with a fear of getting things wrong. However, as they progressed, their confidence in reading graphs and interpreting data increased. One student noted that they enjoyed diving deeper into the study and understanding of the complexity of the immune system and what it takes to gather a complete understanding of a research paper. Overall, this was an effective, well-received activity to help students build their engagement with the scientific process, quantitative reasoning and technical skills in immunology, allowing the instructor to foster higher-level thinking and optimize student learning in this writing-intensive course.

4 Assessment processes and tools

Focusing on the learning goals before designing an assessment (Table 1), that is adopting a backward-design approach to assessments, is critical to ensure that we are indeed assessing what is important. Assessments with the use of PSL-I can vary considerably depending on the instructor's learning goals, and there is no one-size-fits-all approach (Table 2). Here we discuss different categories for PSL-I related assessments that may provide instructors with a context to plan their own:

i) Student learning gains in immuno-competencies: a list of competencies that undergraduate students in immunology courses can develop are described in the ImmunoSkills guide (Pandey et al., 2024). These competencies are aligned with those listed in the *Vision and Change* report, with two additional unique to ImmunoSkills guide: 1) ability to perform basic lab procedures and 2) ability to explain and/or perform laboratory methodology to address an immunology-based research question. Our respective approaches are aligned with these competencies (Table 1). Since publication of the *Vision and Change* report, several tools have been developed to assess various competencies, that can help instructors to evaluate their students on various measures such as their ability to apply the process of science (Sirum and Humburg, 2011), their scientific reasoning or argumentation skills (Timmerman et al., 2011; Gormally et al., 2012), their knowledge of experimental design (Dasgupta et al., 2014), statistical reasoning skills (Deane et al., 2016), scientific communication (Pisano et al., 2021), and interdisciplinary science thinking (Tripp and Shortlidge, 2020). In addition, VALUE rubrics[7] have been developed to measure a myriad of other competencies such as civic engagement, critical thinking, teamwork, ethical reasoning, etc.

ii) Student learning gains of immunology concepts and terms: in addition to competencies, PSL-I can also reinforce concepts and terms. A group of educators recently identified a set of concepts[8] and topics deemed important for undergraduate students to comprehend (Porter et al., 2021). While development of validated assessment tools to assess immune literacy are in-process by the ImmunoReach Research Coordination Network, the list of concepts provided can help instructors adopt a backward-design approach to plan their own assessments. These assessments can be of varied types ranging from selected response to figure annotation with each having their own advantage and disadvantage (Drew Jennifer et al., 2021). In addition, instructors have previously identified a set of basic biology and immunology-relevant terms and topics [Table 6 in Shah et al. (2025)] that students should know before taking on advanced immunology-specific concepts covered in PSL-I.

When assessing PSL-I, all four instructors could include questions specific to each competency, and address challenges associated with immunology jargon and techniques. The idea of leading students through primary literature can seem daunting at first. However, the impact on student learning can be dramatic. During the process, there are many "aha" moments where students comprehend material or concepts for the first time. Students start to think more scientifically, identifying dependent and independent variables and applying positive and negative controls in various assessments. They start to not only read the papers but analyze and critique them. These student learning gains are especially evident when PSL is used throughout the semester.

5 Discussion: recommendations, limitations and future directions

PSL-I can be a powerful active learning tool that can help keep students and instructors maintain currency, provide context for lab techniques, foster critical thinking, and bolster science identity and belonging. These skills align with core competencies in *Vision and Change* and the ImmunoSkills Guide (Table 1). Through discussion, reflection and comparison, we have identified four distinct ways that PSL-I can be successfully integrated and scaffolded into the undergraduate immunology classroom. For instructors looking to incorporate PSL-I as a single technique, figure, or entire paper into their undergraduate immunology classrooms, these methods require different preparation, classroom time, and grading commitments (Table 2). After discussing these methods, we have three key recommendations:

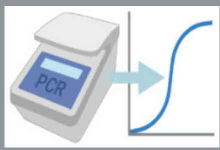
i) Backward design approach to PSL-I integration: identifying clear learning goals and aligning assessments to them is critical to mindful pedagogical practice. For this, we recommend using the ImmunoSkills guide or immunology learning frameworks as a repository of competencies and concepts, and using assessment tools as noted above. The approach should depend on whether the learning goal is to interpret data in graphs or to figure out the basic question and conclusions of a primary article. Instructors may also consider including both formative and summative assessments as well as pre- and post-assessments to help gauge learning gains. As long as it is aligned with the learning goals, the type of assessment can vary based on instructional needs and modality in which the class is offered (e.g., face-to-face, online or hybrid). In our experience, applying and refining the backward-design approach to PSL-I is an iterative process, and often a collaborative approach to this can help lighten the burden by sharing experiences and providing meaningful feedback to each other. The Supplementary material provides example of formative and summative assessments that instructors can adopt.

ii) Scaffolding: scaffolding is an important instructional strategy to break a complex task into smaller ones, to reduce a cognitive load on students (Wyse and Soneral, 2018). PSL is complex and PSL-I is even more so due to complicated techniques, figure types,

7 AACU (2023).

8 Pandey et al. (2023).

TABLE 2 Comparison of PSL-I integration methods by learning environment and implementation strategies.

Learning environment, grading and modality	Figure interpretation/technology of the week (S2) 	Journal-Club (S3) 	Jigsaw (S4) 	5E (S5) 
Typical enrollment	10–20 Biology majors	8–10 Biology majors	14–24 Biology, Biochemistry, and Neuroscience majors	10–15 Biology majors
Prerequisites (with a lab)	Principles of biology; genetics; cell biology	Introductory Biology I	Introductory Biology I and II; Genetics	Microbiology and/or Genetics
No. Of manuscripts handled in a term; time for instructor preparation	1 figure in ∼10 manuscripts	4–5 manuscripts read; questions and answer keys developed	3 manuscripts read; questions and answer keys developed	Deep dive into 1–2 manuscripts over a term
Student time Required for Each Activity	10–15 min of ∼10 class days	Full 50-min class period; Tutorial assignment before class	Full 50-min Class Period; Written summary after class	1-2 h per day
Grading of class work	None, students self-assess	Participation in class discussion	Participation in class discussion	Not applicable in an online, asynchronous course.
Formative grading of work	None	Tutorial assignments	Discussion feedback	Yes, on all weekly responses
Summative grading	Data interpretation example on exams	Tutorial assignments with feedback incorporated; Basic findings of paper on exams	Journal Article Summaries with feedback incorporated	Completion of all weekly assignments, with feedback incorporated
Feasible for synchronous online/hybrid classes?	Yes	Yes	Yes	Yes
Feasible for larger class sizes?	Yes	No, too time intensive to grade	Yes, with help on grading summaries	Yes, but time consuming
Feasible for asynchronous classes?	Yes	Not with group work	Not with group work	Yes

concepts, jargon and abbreviations. We recommend providing well-scaffolded background information for students on both the techniques and any jargon or abbreviations commonly used in the paper, addressing the major challenges with PSL-I previously identified. We also suggest breaking up PSL-I comprehension into smaller, manageable tasks that are spaced out to help students meaningfully engage with the PSL-I. The assignments, activities, and worksheets shared as the Supplementary materials of this article are likely to help instructors in this process. It is often beneficial to start with an easier figure, technique or paper at the beginning of the term to enhance student confidence and comfort with this type of activity, and gradually increase the difficulty as the course progresses.

iii) PSL-I choice: choosing an appropriate paper is critical, especially when students must comprehend them to meet the learning goals. An instructor may choose a paper that explores a historic scientific breakthrough, such as the efficacy of a vaccine, or a cutting-edge technology such as immunotherapy, or be of relevance to the instructor's own research expertise. In any case, the paper should have clearly communicated data, adequately written methods, and easily discernible conclusions. Primary articles that use engaging figures and clear diagrams are helpful. Since paper selection for undergraduate audiences can be a daunting and time-consuming task, we have curated a list of primary research articles that have been vetted by instructors in an undergraduate immunology classroom and is freely available for the immunology instructor community to access through this link[9]. In addition, we invite all educators to contribute their own selections to this living resource using a Google form available on this website[10].

It is important to note that the activities described in this manuscript have been implemented in small to mid-sized institutions with small class sizes (see Table 2). The wider feasibility needs to be tested in different contexts, including different modalities (online, hybrid, asynchronous), larger class sizes, or larger institutions with better access to immunology-based research and lab infrastructure. In addition, the type of institution determines curriculum design. We all teach stand-alone, upper-level Immunology courses. The approach and recommendations

9 ImmunoReach (2025b).

10 ImmunoReach (2025a).

might vary considerably if instructors have undergraduate majors in immunology or when immunology is taught in the context of microbiology or human physiology. Going forward, it will be necessary to analyze the effectiveness of these methods. Assessing the impact of figure interpretation/technique of the day, journal club, jigsaw, and 5E approaches will help demonstrate the suitability of these methods.

Immunology is a rapidly growing field and impacts on the daily lives of many. Therefore, having an educated public and scientific community is essential. We presented four methods to incorporate PSL-I in a structured class environment with well-scaffolded activities to achieve many important transferrable and translatable skills from *Vision and Change* and the Immunology Learning Frameworks. For students entering the workforce, graduate, or professional school, the ability to read and critically analyze a PSL article is an important skill. Not all students leave their undergraduate education with the experience and ability to think about research techniques, figures, and results in a critical way. It is an advantage we can give our students as they move forward with their education and careers.

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

RB: Project administration, Writing – review & editing, Writing – original draft, Methodology, Visualization, Investigation, Data curation, Conceptualization. HB: Investigation, Writing – original draft, Visualization, Conceptualization, Writing – review & editing, Methodology. SC: Visualization, Investigation, Methodology, Conceptualization, Writing – original draft, Writing – review & editing. SP: Methodology, Data curation, Writing – original draft, Conceptualization, Funding acquisition, Investigation, Resources, Writing – review & editing, Visualization.

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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.

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

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/feduc.2025.1606578/full#supplementary-material

References

AAAS (2011). *The American Association for The Advancement of Science. (2011) Vision and change in undergraduate biology education: A call to action.* Available online at: https://www.aaas.org/sites/default/files/content_files/VC_report.pdf (Accessed February 22, 2024).

AACU (2023). *The VALUE Rubrics: American Association of Colleges and Universities*. Available online at: https://www.aacu.org/initiatives/value-initiative/value-rubrics (Accessed February 22, 2024).

AAMC (2025). *Scientific Foundations for Future Physicians. Report of the AAMC-HHMI Committee.* Available online at: https://www.aamc.org/system/files?file=2020-02/scientificfoundationsforfuturephysicians.pdf (Accessed April 1, 2025).

Abdullah, C., Parris, J., Lie, R., Guzdar, A., and Tour, E. (2015). Critical analysis of primary literature in a master's-level class: effects on self-efficacy and science-process skills. *CBE Life Sci. Educ.* 14:ar34. doi: 10.1187/cbe.14-10-0180

Anderson, A. E., Justement, L. B., and Bruns, H. A. (2020). Using real-world examples of the COVID-19 pandemic to increase student confidence in their scientific literacy skills. *Biochem. Mol. Biol. Educ.* 48, 678–684. doi: 10.1002/bmb.21474

Antibody Society (2025). *Antibody therapeutics approved or in regulatory review in the EU or US*. Available online at: https://www.antibodysociety.org/resources/approved-antibodies/ (Accessed April 1, 2025).

Brennan, N., Edwards, S., Kelly, N., Miller, A., Harrower, L., and Mattick, K. (2014). Qualified doctor and medical students' use of resources for accessing information: what is used and why? *Health Inf. Libr. J.* 31, 204–214. doi: 10.1111/hir.12072

Brinkmann, V., Reichard, U., Goosmann, C., Fauler, B., Uhlemann, Y., Weiss, D. S., et al. (2004). Neutrophil extracellular traps kill bacteria. *Science* 303, 1532–1535. doi: 10.1126/science.1092385

Chatzikyriakidou, K., Tacloban, M. J., Concepcion, K., and Mccartney, M. (2022). The five core concepts of biology as a framework for promoting expert-like behaviors in undergraduates learning how to read primary scientific literature. *J. Microbiol. Biol. Educ.* 23, e00059–e00022. doi: 10.1128/jmbe.00059-22

Clark, I. E., Romero-Calderón, R., Olson, J. M., Jaworski, L., Lopatto, D., and Banerjee, U. (2009). "Deconstructing" scientific research: a practical and scalable pedagogical tool to provide evidence-based science instruction. *PLoS Biol.* 7:e1000264. doi: 10.1371/journal.pbio.1000264

Dasgupta, A. P., Anderson, T. R., and Pelaez, N. (2014). Development and validation of a rubric for diagnosing students' experimental design knowledge and difficulties. *CBE Life Sci. Educ.* 13, 265–284. doi: 10.1187/cbe.13-09-0192

Davies, K. (2007). The information-seeking behaviour of doctors: a review of the evidence. *Health Inf. Libr. J.* 24, 78–94. doi: 10.1111/j.1471-1842.2007.00713.x

Deane, T., Nomme, K., Jeffery, E., Pollock, C., and Birol, G. (2016). Development of the statistical reasoning in biology concept inventory (SRBCI). *CBE Life Sci. Educ.* 15:ar5. doi: 10.1187/cbe.15-06-0131

Dolence, J. J. (2021). Design your own flow cytometry experiment: a four-week inquiry laboratory. *CourseSource.* doi: 10.24918/cs.2021.19. [Epub ahead of print].

Drew Jennifer, C., Grandgenett, N., Dinsdale Elizabeth, A., Vázquez Quiñones Luis, E., Galindo, S., Morgan William, R., et al. (2021). There is more than multiple choice: crowd-sourced assessment tips for online, hybrid, and face-to-face environments. *J. Microbiol. Biol. Educ.* 22:e00205-21. 10.1128/jmbe.00205-21 doi: 10.1128/jmbe.00205-21

Finelli, C., Ebert-May, D., and Hodder, J. (2005). Collaborative learning–a jigsaw. *Front. Ecol. Environ.* 3, 220–221. doi: 10.1890/1540-9295(2005)003[0220:CLAJ]2.0.CO;2

Fink, L. D. (2013). *Creating Significant Learning Experiences: An Integrated Approach to Designing College Courses.* Hoboken, NJ, John Wiley and Sons, Inc.

Flaspohler, M. R., Rux, E. M., and Flaspohler, J. A. (2007). The annotated bibliography and citation behavior: enhancing student scholarship in an undergraduate biology course. *CBE Life Sci. Educ.* 6, 350–360. doi: 10.1187/cbe.07-04-0022

Freeman, S., Eddy, S. L., Mcdonough, M., Smith, M. K., Okoroafor, N., Jordt, H., et al. (2014). Active learning increases student performance in science, engineering, and mathematics. *Proc. Natl. Acad. Sci. U.S.A.* 111, 8410–8415. doi: 10.1073/pnas.1319030111

Global Newswire (2025). *Global Antibody Drugs Market Report 2024: Human Antibodies Segment, which Held the Largest Share in 2023, is Forecast to Grow at a CAGR of 13.4% During 2023–2029*. Available online at: https://www.globenewswire.com/news-release/2024/09/23/2951219/28124/en/Global-Antibody-Drugs-Market-Report-2024-Human-Antibodies-Segment-which-Held-the-Largest-Share-in-2023-is-Forecast-to-Grow-at-a-CAGR-of-13-4-During-2023-2029.html (Accessed April 1, 2025).

Gormally, C., Brickman, P., and Lutz, M. (2012). Developing a test of scientific literacy skills (TOSLS): measuring undergraduates' evaluation of scientific information and arguments. *CBE Life Sci. Educ.* 11, 364–377. doi: 10.1187/cbe.12-03-0026

Gottesman, A. J., and Hoskins, S. G. (2013). Create cornerstone: introduction to scientific thinking, a new course for STEM-interested freshmen, demystifies scientific thinking through analysis of scientific literature. *CBE Life Sci. Educ.*12, 59–72. doi: 10.1187/cbe.12-11-0201

Goudsouzian, L. K., and Hsu, J. L. (2023). Reading primary scientific literature: approaches for teaching students in the undergraduate STEM classroom. *CBE Life Sci. Educ.* 22:es3. doi: 10.1187/cbe.22-10-0211

Gunn, K. E., Mccauslin, C. S., Staiger, J., and Pirone, D. M. (2013). Inquiry-based learning: inflammation as a model to teach molecular techniques for assessing gene expression. *J. Microbiol. Biol. Educ.* 14, 189–196. doi: 10.1128/jmbe.v14i2.542

Hoskins, S. G., Lopatto, D., and Stevens, L. M. (2011). The CREATE approach to primary literature shifts undergraduates' self-assessed ability to read and analyze journal articles, attitudes about science, and epistemological beliefs. *CBE Life Sci. Educ.* 10, 368–378. doi: 10.1187/cbe.11-03-0027

Hoskins, S. G., Stevens, L. M., and Nehm, R. H. (2007). Selective use of the primary literature transforms the classroom into a virtual laboratory. *Genetics* 176, 1381–1389. doi: 10.1534/genetics.107.071183

ImmunoReach (2025a). *ImmunoReach: Primary Scientific Literature in Immunology*. Available online at: https://immunoreach.net/primary-scientific-literature-in-immunology-psl-i/ (Accessed April 1, 2025).

ImmunoReach (2025b). *ImmunoReach: Primary Scientific Literature in Immunology (PSL-I) Database*. Available online at: https://airtable.com/apphAXXkSrsKNNI2E/shrXcajkq35nUirkN/tblx0k2CWIRgtm2ti (Accessed April 1, 2025).

Irby, D. M., Cooke, M., O'Brien, B. C. (2010). Calls for reform of medical education by the Carnegie foundation for the advancement of teaching: 1910 and 2010. *Acad Med.* 85, 220–227. doi: 10.1097/ACM.0b013e3181c88449

Kozeracki, C. A., Carey, M. F., Colicelli, J., and Levis-Fitzgerald, M. (2006). An intensive primary-literature–based teaching program directly benefits undergraduate science majors and facilitates their transition to doctoral programs. *CBE Life Sci. Educ.* 5, 340–347. doi: 10.1187/cbe.06-02-0144

Lie, R., Abdullah, C., He, W., and Tour, E. (2016). Perceived challenges in primary literature in a master's class: effects of experience and instruction. *CBE Life Sci. Educ.* 15:ar77. doi: 10.1187/cbe.15-09-0198

Marbach-Ad, G., Briken, V., Frauwirth, K., Gao, L.-Y., Hutcheson, S. W., Joseph, S. W., et al. (2007). A faculty team works to create content linkages among various courses to increase meaningful learning of targeted concepts of microbiology. *CBE Life Sci. Educ.* 6, 155–162. 10.1187/cbe.06-12-0212 doi: 10.1187/cbe.06-12-0212

Morán, J. M., González-Polo, R. A., Soler, G., and Fuentes, J. M. (2006). Th1/Th2 cytokines: an easy model to study gene expression in immune cells. *CBE Life Sci. Educ.* 5, 287–295. doi: 10.1187/cbe.05-07-0092

Morgan, D. E. (2022). Introducing immunology research literature to understand B-cell receptor gene expression. *CourseSource.* 9. doi: 10.24918/cs.2022.36

Mulnix, A. B. (2003). Investigations of protein structure and function using the scientific literature: an assignment for an undergraduate cell physiology course. *Cell Biol. Educ.* 2, 248–255. doi: 10.1187/cbe.03-06-0025

Nature Index (2025). *Science is getting harder to read. From obscure acronyms to unnecessary jargon, research papers are increasingly impenetrable – even for scientists*. Available online at: https://www.nature.com/nature-index/news/science-research-papers-getting-harder-to-read-acronyms-jargon (Accessed April 1, 2025).

Pandey, S., Bruns, H. A., Condry, D. L. J., Justement, L. B., Kleinschmit, A. J., Liepkalns, J., et al. (2023). *CourseSource Immunology Learning Framework.* CourseSource. Available online at: https://qubeshub.org/community/groups/coursesource/courses/immunology/ (Accessed February 23, 2024).

Pandey, S., Elliott, S. L., Liepkalns, J., Taylor, R. T., Vanniasinkam, T., Kleinschmit, A. J., et al. (2024). The immunoskills guide: competencies for undergraduate immunology curricula. *PLoS ONE* 19:e0313339. doi: 10.1371/journal.pone.0313339

Pien, L. C., Colbert, C. Y., Hoyt, A., and French, J. C. (2022). Current trends in medical education affecting allergy and immunology physicians and learners. *Ann. Allergy Asthma Immunol.* 128, 248–255. doi: 10.1016/j.anai.2021.10.012

Pisano, A., Crawford, A., Huffman, H., Graham, B., and Kelp, N. (2021). Development and validation of a universal science writing rubric that is applicable to diverse genres of science writing. *J. Microbiol. Biol. Educ.* 22:e00189-21. doi: 10.1128/jmbe.00189-21

Porter, E., Amiel, E., Bose, N., Bottaro, A., Carr, W. H., Swanson-Mungerson, M., et al. (2021). American association of immunologists recommendations for an undergraduate course in immunology. *ImmunoHorizons* 5, 448–465. doi: 10.4049/immunohorizons.2100030

Ramos Goyette, S., and Deluca, J. (2007). A semester-long student-directed research project involving enzyme immunoassay: appropriate for immunology, endocrinology, or neuroscience courses. *CBE Life Sci. Educ.* 6, 332–342. doi: 10.1187/cbe.07-01-0001

Round, J. E., and Campbell, A. M. (2013). Figure facts: encouraging undergraduates to take a data-centered approach to reading primary literature. *CBE Life Sci. Educ.* 12, 39–46. doi: 10.1187/cbe.11-07-0057

Sato, B. K., Kadandale, P., He, W., Murata, P. M. N., Latif, Y., and Warschauer, M. (2014). Practice makes pretty good: assessment of primary literature reading abilities across multiple large-enrollment biology laboratory courses. *CBE Life Sci. Educ.* 13, 677–686. 10.1187/cbe.14-02-0025 doi: 10.1187/cbe.14-02-0025

Segarra, V. A., and Tanner, S. (2015). Comparing outdated and updated textbook figures helps introduce undergraduates to primary literature. *J. Microbiol. Biol. Educ.*16, 90–92. doi: 10.1128/jmbe.v16i1.892

Seymour, E., Wiese, D., Hunter, A., and Daffinrud, S. M. (2000). "Creating a better mousetrap: On-line student assessment of their learning gains," in *National Meeting of the American Chemical Society* (National Institute of Science Education, University of Wisconsin-Madison), 1–40.

Shah, A. P., Leininger, E. C., and Pandey, S. (2025). Integrating neuroscience and immunology core concepts to develop a neuroimmunology curriculum. *Front. Educ.* 10:1502521. doi: 10.3389/feduc.2025.1502521

Sirum, K., and Humburg, J. (2011). The experimental design ability test (EDAT). *Bioscene* 37, 8–16. Available online at: https://files.eric.ed.gov/fulltext/EJ943887.pdf

Stevens, L. M., and Hoskins, S. G. (2014). The CREATE strategy for intensive analysis of primary literature can be used effectively by newly trained faculty to produce multiple gains in diverse students. *CBE Life Sci. Educ.* 13, 224–242. doi: 10.1187/cbe.13-12-0239

Tanner, K. D. (2010). Order matters: using the 5E model to align teaching with how people learn. *CBE Life Sci. Educ.* 9, 159–164. doi: 10.1187/cbe.10-06-0082

Timmerman, B. E. C., Strickland, D. C., Johnson, R. L., and Payne, J. R. (2011). Development of a 'universal' rubric for assessing undergraduates' scientific reasoning skills using scientific writing. *Assess. Eval. High. Educ.* 36, 509–547. doi: 10.1080/02602930903540991

Tripp, B., and Shortlidge, E. E. (2020). From theory to practice: gathering evidence for the validity of data collected with the interdisciplinary science rubric (IDSR). *CBE Life Sci. Educ.* 19:ar33. doi: 10.1187/cbe.20-02-0035

University of Utah Health Academic Medical Center (2025). *Why a PhD in Microbiology and Immunology?* Available online at: https://medicine.utah.edu/pathology/microbiology-immunology/phd/why-phd-mi (Accessed April 1, 2025).

Wiggins, G., and Mctighe, J. (2005). *Understanding by Design, 2nd Edition*. Association for Supervision and Curriculum Development, Alexandria, VA, USA,

Wyse, S. A., and Soneral, P. A. G. (2018). "Is this class hard?" defining and analyzing academic rigor from a learner's perspective. *CBE Life Sci. Educ.* 17:ar59. doi: 10.1187/cbe.17-12-0278

Xu, B., Luo, Q., Gong, Y., Li, J., and Cao, J. (2021). TLR7 expression aggravates invasive pulmonary aspergillosis by suppressing anti-aspergillus immunity of macrophages. *Infect Immun.* 89:e00019-21. doi: 10.1128/IAI.00019-21

Yao, Z., Lin, Z., and Wu, W. (2023). Global research trends on immunotherapy in cancer: a bibliometric analysis. *Hum. Vaccin. Immunother* 19:2219191. doi: 10.1080/21645515.2023.2219191