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Making immunology inclusive: a low-cost, high-impact activity for exploring T cell receptor diversity

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The function of the immune system is to protect and keep us safe. The immune system surveillance will protect us from foreign antigens entering our body and rogue cells that are no longer under cell cycle control. Considering the most recent pandemic, our students must understand how our immune system works and the function of essential cells involved in this system. However, due to curriculum constraints, particularly at the community college, it may not be feasible for non-biology majors or biology majors to experience the fascinating inner workings of the immune system. Undergraduate students enrolled in an introductory biology, immunology, or microbiology course may not fully grasp the magnitude of receptor diversity embedded in our T cells. The creation of an in-class activity highlights the T cell receptor and provides a deeper understanding of T cell receptor (TCR) diversity. Instructors can use the activity in a lecture or laboratory setting where students work in small groups and use clay to construct different TCRs. Students explore TCR diversity using an interactive V(D)J table of antigen codes. The activity sought to engage students in the classroom to reinforce how T cell diversity contributes to the receptor recognizing the many antigens our bodies encounter daily. The ASPECT (Assessing Student Perspective of Engagement in Class Tool) survey was used to determine students' level of collaboration within their group and their experience with the activity. Results show that students welcomed the activity and felt their contributions and actions during the activity promoted learning.

KEYWORDS

T cell receptor, major histocompatibility complex, active learning, immunology, adaptive immunity, immunology education

1 Introduction

The immune system protects against external and internal threats. It monitors the presence of viruses, bacteria, fungi, parasites, and cells that have ignored cell cycle checkpoints. This complex, highly coordinated system involves various cellular and molecular players, each contributing to the organism's defense through an intricate network of signals, receptors, and responses (Anderson, 2018). The adaptive immune response, a significant player in the body's defense system, is a marvel of specificity and memory (Anderson, 2018). T cells, with their TCR, interact with major histocompatibility complexes (MHCs). These T cells are unique because their TCRs can recognize and respond to various antigens due to somatic recombination events known as V(D)J recombination. Most recently, these unique genetic rearrangements play a crucial role in recognizing fragments of the SARS-CoV-2 virus (Wang et al., 2021).

The COVID-19 pandemic was declared over by the World Health Organization in 2023 (Wise, 2023). In the wake of these devastating events, there is an urgent need for conversations about the essential workings of the immune system in the classroom. Whether a student is a STEM or non-STEM major, understanding immunological facts is crucial to highlight immune system functions and explain why the complex nature of this system is essential for our survival. Providing students with engaging, experiential learning opportunities centered around TCRs is a steppingstone to improving their scientific knowledge and enabling them to make informed decisions about their health and participate more actively in public health and biomedical research discussions. Unfortunately, curriculum limitations may prevent thorough exploration of immunology, especially at community colleges.

In 2-year institutions, courses such as introductory biology, anatomy and physiology, and microbiology must tackle a broad array of content within a short timeframe, making it challenging to explore specialized and complex areas of the immune system, including TCR genetics in great depth. Four-year biology programs offer immunology as an upper-level course. However, such upper-level courses require a sufficient understanding of biological facts, and as noted by Kahlon et al. (2022), an accurate understanding of immunology function correlates with coursework and the number of years in college. To address the issue of the lack of immunological knowledge, instructors may need to expand their pedagogical toolbox to enhance student understanding of complex immunological mechanisms by designing active learning exercises that engage novice students. Furthermore, activities that address different learning styles, such as kinesthetic learning, have been shown to support more profound understanding and engagement (Tranquillo, 2008). Thus, deeper cognitive engagement will enhance critical thinking skills, scientific curiosity, and confidence when activities focus on a specific scientific topic with clear goals. On a broader lens, this work aligns with trends in STEM education that support efforts to improve inclusivity, engagement, and real-world relevance (BrckaLorenz et al., 2021; Adetunji et al., 2023). As educators, we are responsible for teaching facts, encouraging curiosity, and developing student confidence from all backgrounds. Providing accessible and relevant biology experiences helps level the playing field and demonstrates to students that they can succeed and find enjoyment in science. Thus, creatively implementing constructivist ideas through active learning in the classroom can accomplish this.

Constructivism argues that learning occurs through one's ability to build on previous experiences within the context of mental ability (Piaget, 1980) and independent learning rather than receiving facts from an instructor (Vygotsky, 1962). In this framework, learning is most effective when students are engaged in authentic, meaningful tasks that require inquiry, problem-solving, and reflection (Williams, 2017). Group discussions, case studies, hands-on modeling, and simulations align closely with constructivist principles by involving students in the learning process (Prince, 2004). By blending these strategies, students are introduced to new perspectives and can apply concepts to the real-world, thus promoting deeper understanding and long-term retention (Allen, 2022). Constructivism also promotes a facilitatory role for classroom instructors, where instructors guide learners through scaffolded activities that promote critical thinking and

metacognition, both necessary for mastering complex biological systems. Lastly, the practice of constructivism in the classroom can narrow learning gaps among all student populations (Haak et al., 2011; Theobald et al., 2020; Allen, 2022).

Tactile teaching tools with guided inquiry learning fall under the umbrella of constructivism and promotes student engagement and inclusivity.¹ Visual aids and interactive modeling, have been shown to be effective in promoting student learning and knowledge retention in a range of biological disciplines (Motoike et al., 2009; Bareither et al., 2013; Gordy et al., 2020; Harris et al., 2022).

This work proposes a simple, scalable in-class activity that promote a more profound understanding of complex scientific concepts, like TCR diversity among undergraduate students.

2 Clay modeling: the V(D)J-MHC antigen activity

Students in a non-major biology course at a predominantly urban, Hispanic-serving 2-year institution participated in the TCR-MHC antigen activity. The non-major course is part of the general education curriculum, where students must take a science course with a laboratory component. The course met for 3 h each week and covered core biological concepts, the scientific method, chemistry, ecology, and evolution. A diverse student body participated in the activity major, including Business Administration, Computer Science, English, Psychology, Journalism, and Mental Health majors.

The pedagogical method of teaching TCR diversity can be adapted to suit a wide range of undergraduate learners, including non-STEM majors, allied health students, and those pursuing STEM degrees. The activity allows students work in small collaborative groups to model TCRs using clay. In addition, the activity's flexible design allows for modification for introductory biology, immunology, microbiology, and human anatomy and physiology courses. The method is suitable for implementation in both 2-year and 4-year college and university settings, ensuring accessibility and relevance regardless of institutional type. Furthermore, the activity can meet diverse student needs while promoting engagement with one of the most intricate aspects of adaptive immunity.

2.1 Implementation

A 45-to-60-min lecture on the immune system before the start of the activity. The lecture was based on Chapter 25: Endocrine and Immune Systems from Houtman's *Biology Now, With Physiology*, 3rd edition (Houtman et al., 2021), which introduced the innate and adaptive immune systems. Lecture material on the major histocompatibility complex was retrieved from Chapter 20 of Ammerman's *Human Anatomy and Physiology*,

¹ <https://qubeshub.org/community/groups/stembuild/overview>

TABLE 1 Table of VDJ Codes.

	D1	D2	D3	
V1	Egg shape	Small sphere	Medium sphere	J1
	Paper clip	Heart shape	Small square	J2
	Letter 'X'	Cube with each side measuring 2 cm	Rectangular prism 2 cm X 1 cm	J3
V2	Plus sign	Medium shallow circle	Small shallow circle	J1
	Cube with each side measuring 4 cm	Square sides = 1 cm	Rectangle 2 cm X 1 cm	J2
	Pyramid	Cylinder	Small foil ball	J3
V3	Any shape made with foil	Two small squares	Rhombus	J1
	Two small circles	Triangle with rectangle	Three small circles	J2
	Two triangles	Circle with rectangle	Three small squares	J3

The object students will create is determined by on the unique sequence of their individual wheel picker spins.

2nd edition (Ammerman, 2018). Learning outcomes, lecture outline, and instructions can be found in [Supplementary Figure 1](#).

Following the lecture, students viewed a 1:39 video on the theory behind creating their unique TCR ([Supplementary Figure 2](#)). To mimic the random nature of genetic recombination, a wheel picker allowed students to produce a unique MHC-presenting cell's antigen ([Table 1](#); [Supplementary Figure 1](#)). Students then used clay to model the antigen and the unique TCR shape. Images of student's work can be found in [Supplementary Figure 3](#).

3 Activity engagement and outcomes

Pre- and post-surveys can assess the effectiveness of active learning activities by measuring changes in student understanding, confidence, or attitudes before and after an intervention (Davis et al., 2017). One significant advantage is that they provide a structured way to capture students' foundational knowledge or perceptions, which can then be compared to outcomes following the activity (Domenghini et al., 2014; McDevitt et al., 2016). Data assessment can help instructors determine whether their teaching strategies meet their desired learning goals. Additionally, when designed thoughtfully, surveys can highlight specific areas where students improved or continued to struggle, guiding future instruction, and activity refinement.

However, there are limitations to using pre- and post-surveys. One common challenge is ensuring that survey questions align with the learning objectives and are interpreted consistently by students. There's also a risk of response bias; students might overestimate or underestimate their understanding, especially when answering self-assessment questions. Moreover, surveys typically measure perceived learning rather than actual performance, which may not accurately reflect gains in knowledge or skills. Surveys should be combined with other forms of assessment, such as performance tasks or reflective writing, to get a more complete picture of learning outcomes.

3.1 Value of group activity on TCR diversity

ASPECT (Assessing Student Perspective of Engagement in Class Tool) assessed the activity's effectiveness and provided immediate feedback on the activity from students (Wiggins et al., 2017). The following ASPECT categories were used for the activity: value of group activity and personal effort. Five survey items were used to determine the value of group activity: *Explaining the material to my group improved my understanding of it*; *Having the material explained to me by my group members improved my understanding of the material*; *Group discussion during the TCR activity contributed to my understanding of the course material*; *Other members made valuable contributions during the TCR activity*; *I am confident in my understanding of the material presented during today's TCR activity*; *I had fun during today's TCR group activity*. In-class group activities are a valuable pedagogical strategy in undergraduate biology education, primarily when the instructor aims to teach complex concepts like TCR diversity. The effectiveness of the activity lies in its ability to foster peer explanation, encourage group discussion, and promote individual contributions, where each plays a critical role in enhancing student understanding and confidence.

One of the most impactful mechanisms of collaborative learning is peer explanation. When students teach or explain content to one another, they engage in meaningful cognitive processes such as retrieval, elaboration, and synthesis (Chi et al., 1994; Fiorella and Mayer, 2013). As noted by Bargh and Schul (1980), "learning by teaching" illustrates reciprocal benefits in that the explainer reinforces their understanding of the material while helping their peers understand difficult material (Bargh and Schul, 1980; Hoogerheide et al., 2016). In this study, 69% of students reported that group members' explanations improved their understanding. Such explanations are especially beneficial for non-biology majors, who may find scientific terminology challenge. Classmates can translate these concepts into more accessible language, lowering cognitive barriers and making the material more relatable (Topping, 2005; Micari and Pazos, 2012).

In addition to explanation, group discussions play a crucial role in conceptual learning. During the clay modeling activity,

students collaborated in small groups to construct representations of TCRs and antigens. The conversations encouraged students to articulate their reasoning, confront misconceptions, and build shared knowledge (Chi and Wylie, 2014; Smith et al., 2009). Group dialogue exposes students to different perspectives (Webb et al., 2009). Notably, 74% of students agreed that group discussions contributed to their understanding, demonstrating the value of embedding discussion within active learning tasks.

Another essential component of group learning is individual contribution. Active participation, whether through questioning, explaining, or offering analogies, encourages students to externalize their thinking, supporting metacognitive development and revealing gaps in understanding (Roscoe and Chi, 2007). In our study, 90% of participants agreed that their group members made valuable contributions to the activity. Contributions don't need to be correct to be meaningful; they serve as prompts for dialogue and problem-solving that enhance group understanding (Topping, 2005). Contributions also foster accountability, increase motivation, and strengthen students' connection to their peers (Micari and Pazos, 2012).

The activity supported student confidence in understanding. Unlike passive lecture formats, hands-on, collaborative activities engage students in active learning, encouraging deeper processing and retention of complex biological content (Freeman et al., 2014; Allen and Tanner, 2005). Students practiced critical thinking and applied new knowledge in a supportive environment that allowed for clarification and feedback. Sixty-four percent of students reported confidence in their understanding after completing the activity, highlighting the role of interactive learning in building scientific literacy. Finally, in this study, 79% of students reported having fun during the activity, reinforcing the value of positive emotional experiences in supporting motivation, collaboration, and long-term interest in science (Dweck, 2006).

3.2 Personal effort during the TCR diversity activity

Focus group data collected by Wiggins et al. (2017) show that personal effort is highly valued in group activities, which is essential in promoting student engagement. Three survey items were used to determine students' personal effort categories, including *I made a valuable contribution to my group today*; *I was focused during today's TCR activity*; and *I worked hard during today's TCR activity*.

3.2.1 I made a valuable contribution today

Within active learning environments, individual student contributions to group activities are essential for maximizing the educational impact of collaborative work. Group learning emphasizes shared responsibility, and the quality and frequency of individual participation significantly influence both personal and collective learning outcomes. When students articulate their ideas, offer explanations, or ask questions during group tasks, they engage in cognitive elaboration, a process that strengthens understanding through retrieving and restructuring knowledge (Chi and Wylie, 2014; Roscoe and Chi, 2007).

Moreover, when each group member contributes, the activity becomes more inclusive and equitable, ensuring that a few voices do not dominate learning. Students who regularly participate report greater confidence, increased motivation, and a stronger sense of belonging in the classroom (Micari and Pazos, 2012). For instructors, observing individual contributions provides valuable insight into student comprehension and the option to facilitate discussion. For this activity, 84% of students believed they, individually, made a valuable contribution during the TCR activity, and 63% agreed that teaching others strengthened their grasp of TCR diversity.

3.2.2 I was focused and worked hard

When students demonstrate focus and sustained effort during in-class group activities, the value of active learning is strengthened. By remaining focused during the activity, students are better equipped to stay organized, meet objectives, and retain complex information (Michael, 2006). Furthermore, participation and meaningful engagement with their peers and the content are more likely to occur, providing heightened curiosity about the activity. Moreover, a sense of accountability and commitment to the activity's goals are observed with sustained effort. Such qualities will enhance content mastery and transferable skills such as communication, problem-solving, and teamwork, which are career-readiness competencies highlighted by employers (National Association of Colleges and Employers, 2025). From this activity, 84% of students reported they were focused, while 68% reported they worked hard during the activity.

4 Limitations

The activity was implemented in a non-majors biology course at a community college where students lacked extensive backgrounds in biology or immunology. The goal of the activity was to offer an introductory perspective on TCR diversity. Conducted soon after the return to in-person instruction following the COVID-19 pandemic, the exercise was designed to help students address the question of how our immune system protects us from harmful invaders. While the activity fosters engagement, further research is warranted to evaluate its effectiveness in student learning. For example, longitudinal studies could introduce the activity in an introductory general biology course and revisit it in advanced courses such as microbiology or immunology. For allied health majors at community colleges, the activity could be incorporated into human anatomy and physiology as well as microbiology, the latter often taken after anatomy and physiology in many programs.

Additionally, this activity did not include a direct assessment of student learning gains related to TCR diversity. Pre- and post-assessments are recommended for instructors of human anatomy and physiology, immunology, or microbiology courses, to determine learning gains for health science and biology majors. The work of Harris et al. (2022) and others (Motoike et al., 2009; Bareither et al., 2013; Gordy et al., 2020), report that in addition to student engagement, tactile learning activities, like clay modeling

or 3D printing, allow students to externalize mental models of difficult concepts. Thus, bridging the gap between abstract theory and experiential understanding.

5 Conclusion

Computer-based simulations demonstrating T cell diversity have been reported (Norflus and Allen, 2016; Rosati et al., 2017; Shcherbinin et al., 2023), for novice and advanced learners. However, computer-based modeling, in some instances may require knowledge in bioinformatics and computational biology (Pierce et al., 2014). This study highlights the value of integrating experiential, collaborative learning into undergraduate biology instruction, particularly when addressing complex topics like TCR diversity. The clay modeling activity, grounded in constructivist learning theory and active learning, is an effective pedagogical tool for promoting meaningful engagement and deeper conceptual understanding. By transforming an abstract immunological process into a tangible, hands-on experience, the activity offers students an accessible entry point into a topic often reserved for advanced courses and learners.

Furthermore, incorporating peer explanation and group discussion provided opportunities for students to clarify their understanding, confront misconceptions, and co-construct knowledge. These forms of student-led interaction are especially valuable in diverse classrooms, where learners bring varying levels of prior knowledge and confidence in science. The activity also reinforced important skills such as communication, collaboration, and metacognition, competencies central to STEM education and career readiness. Notably, creating a learning environment that encouraged active participation and enjoyment fostered emotional engagement, which enhanced cognitive processing and long-term retention. Although topics in immunology are rigorous, integrating fun and creativity in the classroom supports a safe and inclusive atmosphere conducive to learning.

Ultimately, this activity demonstrates that thoughtfully designed, low-cost instructional tools can demystify advanced scientific content while empowering all students to see themselves as capable participants in science. It offers a scalable model for educators seeking to increase accessibility, relevance, and equity in biology education, particularly at 2-year institutions. Through active learning, students to retain conceptual knowledge, build on this foundation in advanced coursework, and apply their understanding across academic and real-world contexts.

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 author.

Author contributions

CD: Conceptualization, Data curation, Visualization, Writing – original draft, Writing – review & editing.

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Conflict of interest

The author declares 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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Supplementary material

The Supplementary Material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/feduc.2025.1611781/full#supplementary-material>

SUPPLEMENTARY FIGURE 1

Learning outcomes, lecture outline, and instructions.

SUPPLEMENTARY FIGURE 2

Understanding a T cell receptor'. <https://www.youtube.com/watch?v=VGOK5Jwfc74>.

SUPPLEMENTARY FIGURE 3

Images of students' work.

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