

Research Article

Application of PBL-Seminar Teaching in Flipped Classroom of Immunology Course

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Abstract

Problem-based learning (PBL) is an effective method to develop problem analysis and solving ability for students, and Seminar teaching focuses on critical thinking and interpersonal communication skill training through assigned questions and issues discussion. Immunology is an important compulsory course for medical and most biology-major undergraduates. In this study, we introduced both PBL and Seminar approaches (PBL-Seminar) into the flipped classroom teaching of an immunology course. In pre-class phase, students completed self-directed learning mainly via self-built micro-course materials and formed different learning groups for presentation preparation according to the selected Seminar topics. In the classroom, the teacher and students fully discussed the assigned topic based on group presentation. Furthermore, a series of evaluations were conducted by the teacher and students after class, and questionnaires were distributed to the students for the PBL-Seminar experience investigation using a 5-point Likert scale. The responses indicated the effectiveness of PBL-Seminar teaching model, which enhanced student's comprehensive ability to solve complex problems. This teaching model solved the problem of the inadequacy of classroom hours efficiently, transformed teacher-centered model to student-centered model and eventually promoted both teachers' and students' long-term development. This study also provides a new theoretical basis for the teaching reform of immunology course.

Keywords

Flipped Classroom, Immunology, Micro-Video, Problem-Based Learning, Seminar Teaching

1. Introduction

Immunology, as a pivotal and cutting-edge discipline in life sciences, is a compulsory course for undergraduate students majoring in medicine and most biological sciences. The immunological theory is complex and interdisciplinary [1], which poses significant challenges to students. Furthermore,

the rapid advancements in the field of immunology have led to numerous new discoveries and technologies, further complicating the teaching and learning processes in this domain [2, 3].

In recent years, China's undergraduate professional training

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programs have undergone reforms, resulting in a reduction of hours allocated to specialized courses. Consequently, the class hours for immunology in biology majors have been reduced to 32 or 48 hours, considerably fewer than the 50-64 hours designated for medical majors. This change also poses substantial challenges to the traditional lecture-based learning (LBL) model, which heavily depends on extensive class hours. Moreover, this teacher-centered model is not conducive to fostering students' active learning and problem-solving abilities [4]. Therefore, it is imperative to innovate teaching methods and explore new teaching models. Such innovations are necessary not only to resolve the contradictions brought about by reduced class hours and increased teaching complexity but also to transform the passive mode of "giving a man a fish" into the active mode of "teaching a man how to fish".

With the development of information technology, digital tools have deeply integrated into higher education teaching methodologies, driving reforms and innovations in teaching model. The flipped classroom model, originating in the United States [5], has gradually been implemented in universities and colleges worldwide over the past decade [6-10]. Unlike the traditional classroom, this model emphasizes students' comprehensive abilities rather than mere knowledge acquisition and focuses on cultivating active participation, independent thinking, and interactive communication skills. In the flipped classroom model, teachers shift from being the protagonists of classroom teaching to becoming designers of the overall teaching and learning process, while students transform from passive recipients to active constructors of knowledge and skills. Moreover, the flipped classroom addresses the issue of limited classroom time by transferring knowledge dissemination outside the classroom environment. This shift allows more effective utilization of class time for advanced learning activities, thereby enhancing student engagement and significantly improving the interaction between teaching and learning. The change in the roles of teachers and students in the flipped classroom establishes a new teaching relationship, realizing the "student learning-centered" teaching concept.

The flipped classroom typically comprises two phases: knowledge dissemination and knowledge internalization, facilitated through micro-videos and learning platforms to promote independent learning. In the knowledge dissemination phase, teachers provide pre-class self-study materials via appropriate platforms, laying the groundwork for effective classroom interaction. Pre-class self-study is crucial to the flipped classroom, influencing the quality of classroom interactions to a significant extent. Micro-videos are concise, easily expandable, and highly adaptable, making them popular for pre-class activities in flipped classroom [11]. Moreover, micro-videos cater to varying levels of student proficiency, enabling selective and on-demand learning that transcends temporal and spatial limitations. However, due to differing educational goals across disciplines in universities and col-

leges, the difficulty and content of similar courses' micro-video resources can vary significantly. Currently, most online immunology course resources are geared towards medical immunology, rendering them unsuitable for non-medical undergraduates and severely impairing the effectiveness of the flipped classroom model.

Knowledge internalization, a pivotal component of the flipped classroom approach, primarily occurs within the classroom environment. To achieve high-quality teaching activities, teachers must emphasize fostering students' higher-order thinking and comprehensive problem-solving abilities, ensuring an organic integration of knowledge and skills. During implementation, teachers should select appropriate instructional strategies based on course content, such as training mastery, problem exploration, and discussion.

Problem-based flipped classroom represents an inquiry-based learning model where students engage in various explorative activities centred around disciplinary or real-world problems to acquire knowledge and skills, develop inquiry and application capabilities, and gain emotional experiences under the guidance of teachers. Conversely, discussion and construction flipped classroom fosters knowledge construction through student discussions and communication. Problem-based learning (PBL), proposed by American educator Barrow in the 1960s, presents instructional content as problems to stimulate student interest by guiding them to discuss specific issues [12, 13]. PBL facilitates knowledge and skill acquisition, nurtures inquiry and application abilities, and develops emotional experiences [14, 15]. Seminar teaching, tracing its origins to early 19th-century Berlin University [16], requires teachers and students to collaboratively discuss assigned topics, promoting multifaceted and multilayered cognitive interactions. This method aims to enhance academic exchange and improve students' problem-solving, interpersonal communication, and coordination skills [17-19]. One of the fundamental objectives of biology teaching is to cultivate students' spirit of inquiry and investigative abilities. By steering instruction towards problem-solving, guiding students into exploratory learning, and fostering classroom discussions, students can nurture their abilities to identify, analyze, and solve problems while encouraging rational thought and independent analysis. Both PBL and Seminar methods emphasize interaction between teachers and students, as well as among students. Therefore, integrating PBL and seminar teaching within the flipped classroom framework can enhance discussion and reflection, fostering students' comprehensive abilities to solve complex problems.

On the basis of the background above, teaching reform and practice is conducted for the immunology courses in the biology major at science and engineering universities. This study applied PBL and seminar methods within the flipped classroom environment (PBL-Seminar), leveraging a hybrid model of online and offline learning to improve undergraduate academic outcomes.

2. Materials and Methods

This research uses the modules on immunoprophylaxis and immunotherapy as an example to elaborate on the implementation of the entire research design. The module is divided

into three lessons, with the teaching schedule detailed in [Table 1](#). The flipped classroom implementation consists of three stages: pre-class learning tasks, in-class teaching discussions, and post-class summaries. Specific teaching activities are shown in [Table 2](#).

Table 1. Teaching arrangements of immunoprophylaxis and immunotherapy module.

	Lecture Content	Content
Week 1	Traditional vaccines	Characteristics of traditional vaccines, principles of vaccine design, and side effects caused by vaccines
Week 2	New type vaccines	Types and characteristics of genetically engineered vaccines, principles of vaccine design, and side effects caused by new type vaccines
Week 3	Immunotherapy	Principles of common immunotherapy methods and their therapeutic targets

Table 2. Study design of immunoprophylaxis and immunotherapy module.

	Pre-class	In-class	Post-class
Teacher	1. Publish online learning materials and tasks 2. Release the topics for PBL-Seminar and organize the topic selection	1. Clarify key points and difficulties 2. Organize group presentation and PBL-Seminar discussion 3. Summarize in-class interactive activities	1. Q&A 2. Collect course data and evaluation data 3. Reflection and improvement
Student	1. Review the learned knowledge and complete self-direct learning for the new knowledge 2. Select PBL-Seminar topics, form study groups, and work together to complete group tasks	1. Learn through the Rain Classroom app 2. Group presentation and PBL-Seminar topic discussion	1. Review, summarize and expand knowledge 2. Complete a series of evaluations and submit an overview

2.1. Participants

The study was conducted during the fall semester of the 2023/2024 academic year. The immunology course involved 63 junior students majoring in biotechnology at the School of Bioengineering, XX University, China. Approximately 70% of the participants were female, and 30% were male.

2.2. Study Design

2.2.1. Pre-class Phase

Given that the immunoprophylaxis and immunotherapy modules are built upon prerequisite knowledge of the immune response, it is essential to review relevant concepts before introducing new material. Thus, each class's pre-class learning tasks include both a review of previously learned

knowledge and a preview of new content. Initially, a knowledge map was uploaded online to facilitate understanding of the connections between existing and future knowledge. The preview of new material was accomplished through self-directed online learning on the Zhihuishu platform. Students engaged in self-directed learning by watching micro-videos (Chapter 8: Immune Prevention and Control Technology) and utilizing other reference materials provided by the teacher to complete quizzes and discussion topics.

Additionally, the teacher announced the PBL-Seminar module questions at least two weeks in advance (details in [Table 3](#)). To ensure broad student participation, the maximum number of students per topic was capped at 6. Students selected their preferred topics by signing up in group notes. Those who chose the same topic formed a study group. Within each group, members collaboratively developed a detailed explanation of the topic and prepared oral presentation slides.

One member was subsequently chosen as the primary speaker for the presentation. Based on the course content, the teacher notified the relevant groups one week in advance. Then, the

group posted their presentation slides in the QQ learning group two days before the lecture, allowing other students to study and evaluate them.

Table 3. PBL-Seminar topics of immunoprophylaxis and immunotherapy module.

Topics Content		Connections between topics and teaching content/learning goal Content
Week1	1. Development of influenza vaccines	1. Through the examples of the influenza virus variation, help students understand how to identify vaccine targets and the design principles of vaccines
	2. Side effects of COVID-19 vaccines	2. Through case report on the side effects of COVID-19 vaccines, help students understand the potential effects of vaccines on human body
	3. Research progress on immune adjuvants	3. Through the detailed description of adjuvant research progress, help students understand the importance of vaccine ingredients
	4. Research progress on immune durability of inactivated vaccines	4. Through literature research report, help students understand how to improve immune durability of traditional vaccine
Week2	1. Difficulties in the development of mRNA vaccines	1. Help students understand the design principle and preparation protocol of mRNA vaccines
	2. Dendritic cell (DC) vaccine	2. Through the description of DC vaccine, help students understand this new type vaccine and its application in immunotherapy
	3. HPV and HPV vaccines	3. Through the description of HPV, help students understand the preparation protocol of polyvalent vaccine
	4. Research on AI-based epitope prediction method	4. Through the description of AI-based epitope prediction, help students understand the effects of new technology on immune development
Week3	Immunotherapy	1. Help students understand how the microbes are used in immunotherapy
		2. Through case study, help students understand CAR-T treatment in immunotherapy
		3. Through the description of HIV treatment progress, help students understand the difficulty of HIV treatment and combination therapy methods
		4. Through the description of design and preparation of single-domain antibodies, help students understand the role of antibodies played in immunotherapy

2.2.2. In-class Phase

In class, the teacher first provided supplementary explanations (approximately 8 minutes) based on the pre-class learning tasks to clarify complex lecture content. Subsequently, representatives from each group presented their reports on the assigned topics. This was followed by an interactive discussion and Q&A session involving both the teacher and students. Each group's presentation time was limited to 13 minutes, with an additional 6 minutes allocated for discussion and interaction. A total of four groups presented their topics in each class. Following the PBL-Seminar, the teacher conducted a thorough review of the presentations and synthesized the class knowledge, spending about 6 minutes summarizing the key points.

2.2.3. Post-class Phase

The teacher collected the report materials, evaluated the students' presentations, and provided further suggestions to enhance future teaching activities. Classroom performance scores were incorporated into the final grades, reflecting each student's con-

tribution to the group report. Peer evaluations within the group were based on individual members' performance, while inter-group evaluations followed established assessment criteria. Each student's final PBL-Seminar score was derived from a comprehensive evaluation, with 30% coming from teacher evaluation, 40% from intra-group peer evaluation, and 30% from inter-group evaluation. Students reviewed classroom discussions, consulted relevant literature, and submitted a summary of their topic at the end of the semester.

2.3. Data Collection and Analysis

Course evaluation data were obtained through platforms such as Zhihuishu and the Rain Classroom app using their statistical functions. Additionally, a questionnaire survey was conducted at the end of the course to measure participants' satisfaction with the PBL-Seminar teaching model and their perceptions of their own skill development. Responses were recorded using a 5-point Likert scale (1-5, ranging from low to high). Data analysis was performed using SPSS 19.0 software (SPSS, Inc., USA), with results expressed as mean $\pm$

standard deviation (SD).

3. Results

3.1. Application of Micro-video Resources

The primary micro-video resources used in this study were derived from an online course “Introduction to Immunology”, created by the author's team at XX University. The teachers reconstructed the course content according to the syllabus and divided it into 8 chapters for micro-video recording. A total of 47 micro-videos were produced, covering fundamental theories and related techniques in immunology. Each chapter consisted of several micro-videos, ranging from 3 to 18 minutes in length, and each video was accompanied by corresponding quizzes. This micro-course was launched on the Zhihuishu platform (<https://www.zhihuishu.com/>) in 2019 and became officially available to universities and the public during the fall semester of the 2020/2021 academic year. Compared to other online courses, especially in medical immunology, these self-created micro-course resources were more suitable for on-campus students. Background data indicated that videos, particularly those focusing on key points

and difficult concepts, were repeatedly viewed. Micro-videos enable students to make full use of fragmented time, improving the efficiency of pre-class preparation, which is a crucial aspect of the flipped classroom model.

3.2. Teaching and Learning Activities of the Pre-class Phase

Owing to the popularity of smartphones on Chinese campuses, teaching apps have been integrated into the teaching process to help teachers and students record course data. In the pre-class stage, teachers published timed quizzes via the Rain Classroom app and analyzed students' response feedback. Each quiz contained 3 questions. Question 1 assessed students' grasp of basic theory in a single-choice format. Question 2 and Question 3 evaluated students' comprehensive ability to analyze complex problems using multiple-choice formats. The average scores of the three quizzes were 3.8 ± 1.1 , 4.0 ± 1.2 and 3.9 ± 1.1 (out of 5), respectively, with the correct rates for all six questions exceeding 60% (see Table 4). These correct rates indicate that some students still struggle with complex problem-solving.

Table 4. The statistical results of pre-class quizzes ($n=63$).

Average score (out of 5) (Means $\pm$ SD)		Correct rate (%)		
		Question 1	Question 2	Question 3
Quiz 1	3.8 ± 1.1	92.1	42.8	63.5
Quiz 2	4.0 ± 1.2	87.3	60.3	65.1
Quiz 3	3.9 ± 1.1	90.5	52.4	55.6

The effectiveness of self-directed learning was primarily monitored through the Zhihuishu platform, including evaluations of micro-video learning and corresponding online quizzes. Module statistics are shown in Table 5. The “Learning Progress” score represented the completion status of micro-video learning (see Table 5), indicating that all students fully watched the micro-videos. The “Learning Habits” score assessed students' micro-video learning behavior, revealing that most students did not rush to learn new course content (see Table 5). The “Learning Interaction” score rec-

orded and evaluated online interactive behavior (see Table 5), showing that students' attention to online interactions was relatively low. Thirty-six percent of students actively participated in Q&A discussions (scores >6), while 11% never participated (score=0). Preview quizzes, conducted in multiple-choice format, tested students' understanding of the foundational knowledge for new lessons, and results demonstrated that most students performed well and met the learning objectives.

Table 5. The statistical results of self-directed learning effects (Means $\pm$ SD, n=63).

	Score (out of 10)				Total Score (out of 40)
	Learning Progress	Learning Habit	Learning Interaction	Preview Quiz	
Lecture 1	10.0 $\pm$ 0.0	10.0 $\pm$ 0.0	5.2 $\pm$ 3.0	9.5 $\pm$ 0.7	34.7 $\pm$ 3.3
Lecture 2	10.0 $\pm$ 0.0	10.0 $\pm$ 0.0	5.0 $\pm$ 3.1	9.7 $\pm$ 0.5	34.7 $\pm$ 3.1
Lecture 3	10.0 $\pm$ 0.0	9.2 $\pm$ 2.2	3.7 $\pm$ 3.2	9.2 $\pm$ 2.1	31.7 $\pm$ 5.8

In addition to the preview tasks, the topics for PBL-Seminar were also released to students in advance. This module included three lectures: the first focused on traditional vaccines, the second explored new vaccines, and the third concentrated on immunotherapy techniques. The lecture topics were closely related to the content of each session (see Table 3). Students selected topics online through a sequential sign-up process. If the quota for a topic was filled, they had to choose another topic. Students were required to participate in at least one PBL-Seminar group report per semester. Background sign-up data revealed that, topics related to coronavirus vaccines were the most popular in the context of the global COVID-19 pandemic, reflecting the practical relevance of immunology knowledge. Each group conducted an in-depth analysis of their chosen “question” topic and created presentation slides through literature research and repeated discussions. According to the course schedule, the presentation slides were posted in the QQ learning group two days before the lecture, allowing other students to preview and discuss them. Download records indicated that most students studied the slides on time, with only a few failing to complete this task before each lecture.

3.3. Teaching and Learning Activities of the In-class Phase

Each class session was divided into two parts, each lasting 45 minutes. First, the teacher provided a summary of the pre-class task completion, clarifying key points and difficulties, particularly addressing areas where students showed weaker understanding. Subsequently, each group presented their seminar topic within a designated 13-minute timeframe, followed by a 6-minute discussion on the topic. Finally, the teacher briefly commented on the presentation. The teaching process was facilitated through the Rain Classroom app, ensuring that students could easily review the material.

Overall, most groups were well-prepared, accurately covering the key points of the course syllabus in their chosen topics. Reports on topics such as the side effects of corona-

virus vaccines, mRNA vaccines and fecal microbiota transplantation (FMT) were particularly noteworthy for their cutting-edge content, thorough literature research, and detailed case analysis. Additionally, the polished delivery by the presenters made the content more accessible to classmates. Communication and discussion are core elements of PBL-Seminar teaching, which is vital for enhancing cognitive diversity among students. Within the Seminar session, discussions on “trending” topics such as coronavirus and mRNA were notably more vigorous compared to those on less popular subjects. After the group presentations, the teacher provided evaluative comments on the class’s performance, summarized the problem-solving effectiveness of each group, supplemented knowledge areas that were not sufficiently covered or explained, and ultimately organized a comprehensive knowledge framework.

3.4. Teaching and Learning Activities of the Post-class Phase

In the post-class phase, the students reviewed their knowledge through the Zhihuishu platform and the Rain Classroom app. The slides of the teacher and the four groups were stored in the Rain Classroom app for repeated review. Moreover, each student evaluated their team members based on various aspects of their contributions, such as literature research, slide preparation, presentation, and classroom question responses. The average scores for each member, shown in Table 6, suggested significant differences in individual contributions. Notably, the highest-scoring student in each group was usually the presenter, deemed to have made the greatest contribution to the group. Additionally, each group's performance was evaluated by other groups and the teacher based on the quality of their slides (30%), presentations (40%), and seminar discussions (30%). These external evaluation rankings, detailed in Table 7, show consistency between peer and teacher evaluations, with T_5, T_9, and T_2 consistently ranked in the top 3.

Table 6. The statistical results of group member evaluation.

	Average score of group member evaluation (out of 100)					
	Stu_1	Stu_2	Stu_3	Stu_4	Stu_5	Stu_6
T_1: influenza vaccines	90	88	86	90*	91	-
T_2: Side effects of COVID-19 vaccines	92	93	89	92	94*	-
T_3: immune adjuvants	77	89	95*	93	-	-
T_4: immune durability of inactivated vaccines	90	88	92*	88	92	-
T_5: mRNA vaccines	94	95	98*	93	95	94
T_6: DC vaccine	92	75	90	90	87	90*
T_7: HPV and HPV vaccines	96*	94	88	89	90	-
T_8: AI-based epitope prediction	80	80	95*	86	88	-
T_9: FMT	94	92	90	89	97*	94
T_10: CAR-T	95	76	90	97*	75	-
T_11: HIV treatment	85	89*	89	88	-	-
T_12: single-domain antibodies	96*	80	89	90	88	-

*the speaker of group presentation.

Table 7. The statistical results of external evaluation.

	External evaluation (out of 100)	
	Average score by other groups (Means $\pm$ SD, n=11)	By teacher
T_1: influenza vaccines	89.1 $\pm$ 2.3	88
T_2: Side effects of COVID-19 vaccines	92.3 $\pm$ 1.9	93
T_3: immune adjuvants	88.5 $\pm$ 6.0	89
T_4: immune durability of inactivated vaccines	90.2 $\pm$ 2.0	88
T_5: mRNA vaccines	95.0 $\pm$ 1.7	95
T_6: DC vaccine	87.3 $\pm$ 5.2	85
T_7: HPV and HPV vaccines	91.4 $\pm$ 3.4	90
T_8: AI-based epitope prediction	85.8 $\pm$ 6.3	83
T_9: FMT	92.7 $\pm$ 2.9	92
T_10: CAR-T	86.6 $\pm$ 4.4	85
T_11: HIV treatment	89.8 $\pm$ 4.9	87
T_12: single-domain antibodies	88.3 $\pm$ 5.1	85

3.5. Study Assessment

The questionnaire survey results on the PBL-Seminar

flipped classroom model were presented in Table 8. Students recognized the importance and effectiveness of self-built micro-video materials in independent learning (Q2 and Q4). While preparing presentations, students enjoyed the team-

work aspect (Q6) but faced challenges in conducting literature research (Q7) and completing the presentation within the two-week timeframe (Q5). Moreover, students actively participated in problem-oriented seminar interactions (Q8 and Q10) and found these interactions enlightening (Q9). Overall, this model promoted a deeper understanding of new knowledge (Q11), with students highly appreciating the method, finding it more effective than traditional classrooms,

and advocating its further implementation (Q12 and Q13). However, it is worth noting that some students reported feeling anxious and burdened due to the teaching reform (Q3 and Q14). Furthermore, personal skills, including self-directed learning ability, independent thinking ability, communication ability, analysis and solution ability, all showed varying degrees of improvement (Table 9).

Table 8. Students' responses to PBL-Seminar teaching model (n = 63).

Questions	Means $\pm$ SD
Understand the principles of the PBL and seminar methods?	3.84* $\pm$ 0.60
Self-built micro-video materials are more effective for independent learning than other resources?	4.13 $\pm$ 0.63
Preview tasks are heavy workload?	2.84 $\pm$ 0.63
Understand the self-directed learning content well?	4.01 $\pm$ 0.71
The time for presentation preparation is short?	2.80 $\pm$ 0.60
Enjoy in working collaboratively with others?	3.84 $\pm$ 0.63
Feel difficult in conducting literature research?	3.70 $\pm$ 0.61
Participate in discussion actively?	3.59 $\pm$ 0.75
Inspired by others' questions or ideas during discussion?	3.87 $\pm$ 0.83
Defend your own argument during intense discussion?	3.30 $\pm$ 0.72
A deeper understanding of knowledge?	4.16 $\pm$ 0.65
This model is more attractive than traditional class?	3.82 $\pm$ 0.81
Suitable for the current educational situation?	3.92 $\pm$ 0.60
Feel anxious or pressure?	3.34 $\pm$ 0.51

*Responses were on a scale of 1 (strongly disagree) to 5 (strongly agree).

Table 9. Personal gains related to PBL-Seminar learning experience (n = 63).

Questions	Means $\pm$ SD
Increase interest and initiative in learning	3.81 $\pm$ 0.56
Enhance teamwork ability	3.84 $\pm$ 0.45
Enhance scientific research ability	3.71 $\pm$ 0.63
Improve oral expression ability	3.51 $\pm$ 0.59
Cultivate critical thinking ability	3.48 $\pm$ 0.58
Enhance problem solving ability	3.73 $\pm$ 0.63
Deepen the communication between student-student and teacher-student	3.89 $\pm$ 0.67

*Responses were on a scale of 1 (no gains) to 5 (great gains).

4. Discussion

Immunology is a crucial mandatory course for biology majors, requiring students to master the fundamental principles and techniques of immunology. The current focus of education has shifted towards enhancing students' abilities in independent learning, critical thinking, and problem-solving, thereby laying a solid foundation for their future careers, especially in scientific research. However, traditional teacher-centered classrooms increasingly fail to meet these evolving educational needs. Moreover, reduced classroom time poses additional challenges to conventional teaching methods, necessitating a reform of instructional strategies.

Although flipped classrooms and PBL have been widely implemented and studied in global educational practice, they still exhibit certain limitations. The classic PBL model emphasizes learning through problem-solving, but students may sometimes focus too much on "solving the problem" itself, lacking a deep understanding and systematic integration of underlying principles. The flipped classroom approach moves knowledge transmission to the pre-class stage, allowing students to acquire basic knowledge independently through instructional videos, while classroom time is dedicated to deepening understanding and application. However, without structured and guided deep-discussion sessions, the flipped classroom often struggles to ensure that students effectively internalize pre-class self-directed content into a systematic knowledge framework and achieve the advancement of higher-order thinking skills [20]. Simultaneously, some studies indicate that the effectiveness of PBL is influenced by factors such as the quality of problem design, teachers' facilitation skills, and students' preliminary preparation levels. If problems are designed too simply or lack challenge, or if teachers fail to effectively guide discussions toward depth, it may be difficult to sustainably promote students' higher-order thinking development [21].

To address the aforementioned challenges, this study integrates PBL with Seminar teaching (PBL-Seminar) and incorporates it into the practice of a flipped classroom for immunology. The flipped classroom model has been applied to resolve the contradiction between limited teaching time and advanced learning objectives [22-24]. This model relies on pre-class independent learning facilitated by various online resources and platforms. However, most online immunology resources originate from medical courses, and their depth and breadth are often insufficient, making them less suitable for undergraduate science and engineering students. Based on this, the present study developed an online micro-course titled "Introduction to Immunology" based on self-compiled textbooks "Principles and Techniques of Immunology." This course covers the basic principles of the immune system, immune responses, and immunological techniques, aligning closely with the university's curriculum system, and its content is regularly supplemented and updated. A questionnaire survey conducted via the Zhihuishu platform indicated that

students found the self-developed resources made pre-class learning more targeted and effective, thereby laying a solid theoretical foundation for interactive activities in the flipped classroom.

In the PBL-Seminar model, teachers decompose knowledge content into several problems for students to ponder and solve. In this process, the teacher's role shifts from a lecturer to a facilitator, while students, based on their own understanding, assume the role of presenters, sharing knowledge and thereby achieving genuine deep engagement in classroom teaching. This study adopted a group-based rather than individual-based approach to PBL, promoting problem-solving through collective wisdom generated from intellectual collisions, thus enhancing students' teamwork skills, including recognizing and understanding others' perspectives, effective communication, and participatory leadership. To facilitate the comprehension of new knowledge, this study selected relevant issues as topics for in-depth discussion. In the discussion-based teaching model, teachers and students participate equally, respecting each other, learning together, and progressing collectively. Questions and explanations proposed by each group underwent repeated discussions, encouraging students to present their viewpoints from different angles and defend their positions through rigorous debate, thereby fully activating their learning potential. It is noteworthy that the relationship between teachers and students is not antagonistic but dialectically unified. The PBL-Seminar model transforms traditional knowledge transmission into a dynamic process of acquisition, reflection, and internalization.

The PBL-Seminar model addresses the deficiencies of traditional PBL in knowledge system integration and deep reflection by introducing structured Seminar sessions, while also mitigating potential limitations of the flipped classroom in promoting knowledge internalization and higher-order thinking cultivation. By embedding Seminar discussion sessions after the problem exploration and solution construction phases of PBL, this model provides students with a platform to explain, defend, question, and reflect on their problem-solving processes and conclusions. This deep academic dialogue significantly promotes profound knowledge internalization, systematic integration, and meaning construction, effectively resolving the "knowledge without depth" issue potentially present in traditional PBL and the "learning without internalization" problem that may occur in flipped classrooms, thereby markedly fostering deeper interaction and knowledge construction between teachers and students and among students themselves. The Seminar sessions, requiring students to engage in presentations and interactive discussions, not only consolidate the knowledge and problem-solving methods acquired during the PBL phase but also enhance students' abilities in critical analysis, logical reasoning, academic expression, and response to challenges, making the cultivation of students' higher-order thinking skills more explicit and sustainable.

Furthermore, PBL typically relies on group collaboration, but it may lead to "free-riding" phenomena, where individual students contribute less (see Table 6), while more capable students shoulder more tasks. Although peer assessment is one solution, its reliability and validity are often compromised by interpersonal factors, making it difficult to accurately quantify each member's actual contribution [25]. The PBL-Seminar model naturally incorporates multiple process evaluation points, including group collaboration and problem-solving processes during the PBL phase, as well as presentation and performances during the Seminar phase, which can serve as evaluation bases. This allows teachers to conduct more comprehensive, multidimensional, and formative assessments of students' abilities, reducing reliance on single summative assessment results and better aligning evaluation methods with teaching objectives.

Compared to traditional LBL, student-centered teaching models like PBL-Seminar place higher demands on students' autonomous learning ability, time management skills, teamwork capability, and classroom performance confidence. Questionnaire results (Table 8) show that some students struggle to adapt to this shift, constituting a new source of pressure and leading to suboptimal learning experiences [26, 27]. Specifically, the flipped classroom requires students to engage in self-directed learning through videos and other materials before class to prepare for in-depth interaction during sessions. This can induce anxiety among students lacking self-directed learning and self-regulation skills, particularly when they worry about inadequate preparation and inability to participate effectively in classroom discussions [28]. Additionally, the core of PBL and Seminar lies in group discussions, presentation of viewpoints, and debates. Introverted students or those with insufficient oral expression skills may easily develop social anxiety and nervousness in group settings due to concerns about poor performance, fear of being questioned, or receiving negative evaluations [28, 29]. On the other hand, students accustomed to passive knowledge reception generally require an adaptation period when transitioning to new models that demands active exploration and knowledge construction, and the uncertainty associated with new learning methods and evaluation standards itself can induce pressure [30].

The various pressures outlined above contribute to a complex and dynamic relationship between learning pressure and mental health [31]. Well-designed PBL tasks or Seminar discussions can bring a sense of challenge and conquest. Successfully solving complex problems, contributing valuable viewpoints in discussions, and gaining recognition help significantly enhance students' self-efficacy, thereby positively promoting mental health [28, 29]. However, if the academic burden is excessive, tasks far exceed students' current capabilities, or students lack adequate support during the process, persistent and unrelieved stress may lead to anxiety, decreased sleep quality, and diminished self-confidence. In the long term, this can have adverse effects on mental health [31].

To maximize the benefits of innovative teaching models while mitigating their potential negative pressures, educators need to optimize teaching practices through careful design and systematic support [32]. First, teachers should provide clear learning objectives, task instructions, assessment criteria, and necessary scaffolding to help students complete tasks smoothly and reduce stress caused by confusion [28, 29]. Simultaneously, educators should reasonably evaluate task load and difficulty, avoid overlapping multiple complex tasks within the same period, and establish a gradual progression of challenges [28, 32]. Additionally, adopting diversified formative assessments that focus on the learning process, progress, and team contributions, rather than solely emphasizing final outcomes or one-time performances, which can help alleviate students' assessment-related stress [29].

In terms of classroom atmosphere, teachers should emphasize the value of the learning process, encourage experimentation and learning from mistakes, and foster a "fail-safe" environment where students recognize setbacks in exploration as an integral part of learning [28, 29]. Simultaneously, an inclusive communication culture should be established, with clearly defined discussion etiquette that emphasizes mutual respect and active listening, allowing students to gradually adapt and improve their expressive skills [29]. In terms of support systems, schools and universities, on the other hand, should provide relevant training for teachers to enhance their abilities in activity design, discussion facilitation, and identifying students' psychological needs [32, 33]. Additionally, accessible help channels should be established to ensure students know where to seek assistance—whether through teacher office hour consultations, peer support, or professional services from the school's psychological counseling center—when encountering academic difficulties or excessive stress [31].

In fact, teaching models like the flipped classroom, PBL, and Seminar are not the sole sources of student pressure; their effectiveness largely depends on the specific implementation methods and support environment. To effectively manage these challenges and mitigate student pressure, the implementation of PBL-Seminar imposes higher requirements on teachers [28, 29, 32]. Previous studies indicate that teachers often lack sufficient training, support, and resources to effectively implement these models, which may lead to suboptimal implementation outcomes or teacher frustration [25]. In the PBL-Seminar model, the teacher's role is further differentiated and refined: during the PBL phase, the teacher acts as a problem designer and learning guide; during the Seminar phase, the teacher primarily assumes the roles of discussion moderator, deep questioner, and thinking stimulator. Hence, teachers need to invest more time in preparation and skill enhancement, although these skills cannot be acquired in the short term.

Based on above-mentioned issues, multi-level systematic strategies could be adopted to reduce teachers' workload. Firstly, technical support should be leveraged to enhance

preparation efficiency: fully utilize existing high-quality open educational resources and school-based resource repositories to avoid redundant development of materials, and make effective use of the automated functions of online teaching platforms, such as automated quiz grading, to handle routine tasks, thereby saving teachers' time and energy. Secondly, collaborative instructional design and team teaching mechanisms could be implemented [34]. By forming teaching teams to jointly develop resources and design problem chains [35], and distributing guidance responsibilities among different roles, the workload pressure on individual teachers can be effectively alleviated. Simultaneously, schools need to provide systematic professional development support [36], such as offering specialized workshops. Training content should include practical skills like activity design, discussion facilitation techniques, and time management, to enhance teachers' capacity and confidence in implementing new teaching models. Furthermore, reforming evaluation mechanisms is particularly crucial. Workload calculations, performance assessments, and professional promotion systems should fully recognize the implicit efforts teachers invest in course design, resource development, and student guidance, establishing reasonable incentive and compensation systems to comprehensively safeguard teachers' enthusiasm and creativity [37].

With the development of educational technology, the PBL-Seminar model could be integrated with online resources and platforms such as cMOOCs (Connectivist Massive Open Online Courses) and SPOCs (Small Private Online Courses) to build a blended learning environment, expand the temporal and spatial boundaries of learning, promote optimal connection and sharing of resources, and provide more diverse learning resources, more flexible interactive tools, and richer teaching organizational forms for model implementation, indicating broad prospects for future development.

5. Conclusions

On the basis of the self-built online micro-course, the author introduced the PBL-Seminar teaching model into the flipped classroom of the immunology course and fully exploited the strengths of both approaches. This innovative teaching method holds important practical significance in improving learning efficiency and outcomes. In the research design, the PBL method was used for the cultivation of students' independent problem analysis and solving and collaborative skills, while the seminar method was employed to develop students' critical and creative thinking and expression abilities. This teaching model addresses the issue of limited class time by transforming the traditional teacher-centered classroom into a student-centered environment, thereby promoting the long-term development of teachers and students. Overall, this study provides a new theoretical framework for the teaching reform of immunology courses.

Abbreviations

LBL	Lecture-Based Learning
PBL	Problem-Based Learning
PBL-Seminar	PBL and Seminar Methods

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Author Contributions

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Data Availability Statement

The data supporting the outcome of this research work has been reported in this manuscript.

Ethical Considerations

Before the study, approval for this teaching study was ob-

tained from the curriculum development committee and the ethics committee of Qilu University of Technology (Shandong Academy of Sciences) in China. There was no potential harm to participants; anonymity of participants was guaranteed; informed consent of participants was obtained for publication.

Conflicts of Interest

The authors declare no conflicts of interest.

References

- [1] H. A. Bruns, L. B. Justement, Development of a 4-year, comprehensive curriculum model for undergraduate immunology education, *J Immunol*, 204(2020). <https://doi.org/10.4049/jimmunol.204.Supp.222.14>
- [2] A. Bottaro, D. M. M. Brown, J. G. G. Frelinger, Editorial: The Present and Future of Immunology Education, *Front Immunol*, 12(2021). <https://doi.org/10.3389/fimmu.2021.744090>
- [3] H. A. Bruns, J. Deaver, L. B. Justement, Out of the Curricular Shadows: Revolutionizing Undergraduate Immunology Education, *Front Immunol*, 10(2019). <https://doi.org/10.3389/fimmu.2019.02446>
- [4] M. W. Shreeve, Beyond the Didactic Classroom: Educational Models to Encourage Active Student Involvement in Learning, *J Chiropr Educ*, 22(2008) 23-28. <https://doi.org/10.7899/1042-5055-22.1.23>
- [5] A. Sams, J. Bergmann, *Flip Your Classroom: Reach Every Student in Every Class Every Day*, 2012.
- [6] C. Naing, M. A. Whittaker, H. H. Aung, D. K. Chellappan, A. Riegelman, The effects of flipped classrooms to improve learning outcomes in undergraduate health professional education: A systematic review, *Campbell Syst Rev*, 19(2023) e1339. <https://doi.org/10.1002/cl2.1339>
- [7] H. Jung, J. An, K. H. Park, Analysis of satisfaction and academic achievement of medical students in a flipped class, *Korean J Med Educ*, 30(2018) 101-107. <https://doi.org/10.3946/kjme.2018.85>
- [8] S. Sandrone, J. V. Berthaud, C. Carlson, J. Cios, N. Dixit, A. Farheen, J. Kraker, J. W. M. Owens, G. Patino, H. Sarva, D. Weber, L. D. Schneider, Education Research: Flipped classroom in neurology: Principles, practices, and perspectives, *Neurology*, 93(2019) e106-e111. <https://doi.org/10.1212/wnl.00000000000007730>
- [9] M. Barranquero-Herbosa, R. Abajas-Bustillo, C. Ortego-Mat é Effectiveness of flipped classroom in nursing education: A systematic review of systematic and integrative reviews, *Int J Nurs Stud*, 135(2022) 104327. <https://doi.org/10.1016/j.ijnurstu.2022.104327>
- [10] A. Vanka, S. Vanka, O. Wali, Flipped classroom in dental education: A scoping review, *Eur J Dent Educ*, 24(2020) 213-226. <https://doi.org/10.1111/eje.12487>
- [11] Y. Y. Wu, S. Liu, Q. Man, F. L. Luo, Y. X. Zheng, S. Yang, X. Ming, F. Y. Zhang, Application and Evaluation of the Flipped Classroom Based on Micro-Video Class in Pharmacology Teaching, *Frontiers in public health*, 10(2022) 838900. <https://doi.org/10.3389/fpubh.2022.838900>
- [12] N. Bodagh, J. Bloomfield, P. Birch, W. Ricketts, Problem-based learning: a review, *Br J Hosp Med(Lond)*, 78(2017) 167-170. <https://doi.org/10.12968/hmed.2017.78.11.C167>
- [13] E. Arruzza, M. Chau, A. Kilgour, Problem-based learning in medical radiation science education: A scoping review, *Radiography (London, England: 1995)*, 29(2023) 564-572. <https://doi.org/10.1016/j.radi.2023.03.008>
- [14] J. Wosinski, A. E. Belcher, Y. Durrenberger, A. C. Allin, C. Stormacq, L. Gerson, Facilitating problem-based learning among undergraduate nursing students: A qualitative systematic review, *Nurse Educ Today*, 60(2018) 67-74. <https://doi.org/10.1016/j.nedt.2017.08.015>
- [15] K. J. Henderson, E. R. Coppens, S. Burns, Addressing Barriers to Implementing Problem-Based Learning, *AANA J*, 89(2021) 117-124. <https://www.ncbi.nlm.nih.gov/pubmed/33832571>
- [16] H. L. Zeng, D. X. Chen, Q. Li, X. Y. Wang, Effects of seminar teaching method versus lecture-based learning in medical education: A meta-analysis of randomized controlled trials, *Med Teach*, 42(2020) 1343-1349. <https://doi.org/10.1080/0142159X.2020.1805100>
- [17] R. A. Bouwmeester, R. A. de Kleijn, H. V. van Rijen, Peer-instructed seminar attendance is associated with improved preparation, deeper learning and higher exam scores: a survey study, *BMC Med Educ*, 16(2016) 200. <https://doi.org/10.1186/s12909-016-0715-0>
- [18] P. Li, B. Zeng, X. Chen, Z. Liu, J. Yang, Seminar-case learning model improves clinical teaching: a prospective randomized controlled trial, *PeerJ*, 9(2021) e11487. <https://doi.org/10.7717/peerj.11487>
- [19] A. Young, R. Skudutyte-Rysstad, G. Torgersen, E. Giertsen, Teaching Radiographic Caries Detection and Treatment Planning: A Seminar Using an Audience Response System, *Caries Res*, 56(2022) 226-233. <https://doi.org/10.1159/000526109>
- [20] C. K. Lo, K. F. Hew, A critical review of flipped classroom challenges in K-12 education: possible solutions and recommendations for future research. *RPTL*, 12(2017) 4. <https://doi.org/10.1186/s41039-016-0044-2>
- [21] M. Zakaria, S. Maat, F. Khalid, A Systematic Review of Problem Based Learning in Education. *Creat Educ*, 10(2019) 2671-2688. <https://doi.org/10.4236/ce.2019.1012194>
- [22] M. M. Dai, W. B. Qi, X. Y. Chen, M. Liao, Application and exploration of blended learning with BOPPPS teaching model in a veterinary infectious diseases course, *J Biol Educ*, (2022). <https://doi.org/10.1080/00219266.2022.2120904>
- [23] S. Han, Flipped classroom: Challenges and benefits of using social media in English language teaching and learning, *Front Psychol*, 13(2022) 996294. <https://doi.org/10.3389/fpsyg.2022.996294>

- [24] C. Ozcan, Flipped Classroom in Restorative Dentistry: A First Test Influenced by the Covid-19 Pandemic, *Oral Health Prev Dent*, 20(2022) 331-338. <https://doi.org/10.3290/j.ohpd.b3276187>
- [25] Elaine H. J. Yew, K. Goh, Problem-Based Learning: An Overview of its Process and Impact on Learning, *Health Prof Educ*, 2(2016) 2, 75-79. <https://doi.org/10.1016/j.hpe.2016.01.004>
- [26] V. A. Greenwood, C. Mosca, Flipping the Nursing Classroom Without Flipping Out the Students, *Nurs Educ Perspect*, 38(2017) 342-343. <https://doi.org/10.1097/01.NEP.0000000000000167>
- [27] J. M. Puppe, D. M. Nelson, How to Flip the Classroom to Improve Learner Engagement, *J Nurses Prof Dev*, 35(2019) 196-203. <https://doi.org/10.1097/NND.0000000000000537>
- [28] Y. Zhan, X. Wang, Application Research of Flip Classroom Combined with PBL Teaching Method in Psychology Teaching of MBBS Students, *CCME*, 12(2020) 15, 8-10. <https://doi.org/10.3969/j.issn.1674-9308.2020.15.004>
- [29] H. Hu, W. Xu, Reform and Practice of Flipped Classroom Teaching Mode Based on "SPOC+PBL" of Psychostatistics, *Journal of Anqing Normal University (Natural Science Edition)*, 28(2022) 2, 124-128. <https://doi.org/10.13757/j.cnki.cn34-1328/n.2022.02.024>
- [30] L. Wu, R. Su, Learners' Self-Adaptation to Anxiety in Flipped Classrooms in MOOCs, *Journal of Guangxi Science & Technology Normal University*, 3(2014) 88-90. <https://doi.org/10.3969/j.issn.1003-7020.2014.03.024>
- [31] W. Ma, X. Deng, D. Li, The Impact of Overtime Frequency on Teachers' Mental Health: The Chain Mediating Role of Job Burnout and Life Satisfaction, *Journal of Guizhou Education University*, 39(2023) 4, 77-84. <https://doi.org/10.3969/j.issn.1674-7798.2023.04.011>
- [32] E. M. Lan, Unveiling the silent struggle: Investigating the effects of flipped classroom instruction models on business English oral presentation development through online learning: A case of learner engagement, emotions, and anxiety. *Educ Inf Technol*, 29(2024) 23299-23328. <https://doi.org/10.1007/s10639-024-12746-4>
- [33] S. Kavaz, O. Kocak, The Effect of the Online Flipped Learning Model on Secondary School Students' Academic Achievement, Attitudes Towards Their Mathematics Course, and Cognitive Load. *Int J of Sci and Math Educ*, 22(2024) 1709-1737. <https://doi.org/10.1007/s10763-024-10455-5>
- [34] J. C. Clements, B. A. Cord, The Impact of Open Educational Resource (OER) Professional Development on Faculty's Self-Efficacy, Perceived Workload, and Adoption, *J Univ Teach Learn P*, 20(2023) 4. <https://doi.org/10.53761/1.20.4.06>
- [35] H. Tack, R. Vanderlinde, Teacher design teams as a strategy for professional development: a scoping review, *Prof Dev Educ*, 49(2023) 5, 787-803. <https://doi.org/10.1080/19415257.2021.1928076>
- [36] C. K. Lo, K. F. Hew, The impact of flipped classrooms on student learning and teacher workload: A meta-analysis. *Rev Educ Res*, (2024) 100531. <https://doi.org/10.1016/j.edurev.2024.100531>
- [37] E. E. Fairchild, C. A. Taylor, Valuing the invisible work of teaching: A framework for understanding and assessing teaching labor, *JECT*, 31(2020) 2, 5-26.