Performance and Perceptions of Low- and High-Engagement Medical Technology Students through Flipped-Ubiquitous Learning

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***Abstract*—Mastering medical principles, laboratory methods, and interpreting test results poses a significant challenge for medical technology students, particularly when traditional instructional methods limit opportunities for flexible and self-paced learning. To address this issue, this study aimed to enhance teaching time efficiency and improve learning outcomes by transforming traditional instruction into an online-based flipped-ubiquitous learning environment. This innovative approach provided students with flexible, repeated access to key immunology topics anytime and anywhere. The study evaluated the impact of this learning environment on the performance and perceptions of 66 medical technology students enrolled in a fundamental immunology course at a university. An experimental research design was implemented, incorporating pre- and post-test assessments, laboratory evaluations, and a learning perception questionnaire. Repeated measures analysis revealed that the flipped-ubiquitous learning environment significantly improved students' performance. Moreover, students with higher levels of self-engagement exhibited greater performance improvements compared to their lower-engagement peers. Questionnaire responses further indicated positive student perceptions of the learning approach, suggesting that favorable attitudes may contribute to enhanced learning outcomes. The findings highlight the importance of fostering self-engagement and optimizing online learning strategies to support medical technology students in mastering essential knowledge and skills. Recommendations are provided to guide the effective implementation of similar learning models in medical education.**

***Keywords*—higher education, medical technology education, online learning, individual differences**

I. Introduction

The rapid advancement of Information and Communication Technology (ICT) has significantly transformed educational practices, particularly through innovations such as flipped classrooms and ubiquitous learning environments. The flipped classroom model, which integrates online content delivery with in-class active learning, has demonstrated effectiveness in enhancing student engagement, understanding, and motivation across various disciplines, including health sciences [1–3]. However, sustaining student engagement outside the classroom remains a challenge in medical education, as participation levels often vary. Recent studies emphasize that active involvement in pre-class and post-class activities, which are central to flipped learning, plays a critical role in determining the depth of learning outcomes [4, 5]. Moreover, scholars highlighted the significant impact of flipped classrooms on understanding concepts and higher-order thinking skills, suggesting potential applications in medical education [6]. Evidence suggests that students who frequently engage in supplementary learning activities, such as mobile app-based exercises in flipped classrooms, exhibit enhanced performance compared to their less engaged peers [7]. It aligns with findings from ubiquitous learning research, which emphasize that active engagement with mobile and online learning resources often leads to higher levels of understanding and confidence [8]. In health science education, including medical technology, advancements in ICT provide continuous access to learning resources and practical exercises. It not only meets the demands of medical training but also facilitates mastery of complex topics such as immunology [9]. Ubiquitous learning leverages mobile and interactive technologies to enable flexible, location-independent learning, allowing students to engage with content at their own pace and integrate learning into real-world contexts [10]. This flexibility is particularly valuable in medical education, where both theoretical knowledge and laboratory skills are essential for professional growth [11]. That is to say, flipped classrooms could be applied effectively to learning courses, emphasizing the importance of designing tailored and flexible curricula [12].

Integrating the flipped classroom model with ubiquitous learning presents a promising approach to addressing the limitations of traditional methods. Research has shown that providing supportive online environments can significantly enhance student engagement, encouraging the continued use of online learning resources [6]. Studies have also demonstrated that combining flipped classrooms with peer teaching and blended learning effectively supports diverse learners by offering greater flexibility. However, this approach requires well-structured support to maintain consistent engagement and minimize procrastination [4]. By leveraging ubiquitous learning's accessible and immediate tools, students can benefit from a seamless, location-independent learning experience that fosters engagement, motivation, and improved academic performance [8, 13].

Given the complexity of immunology and the critical need

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for practical skills in medical technology education, this study proposed an online-based flipped-ubiquitous learning approach to address the limitations of traditional methods. The flipped classroom model has been widely recognized for its ability to enhance active learning and foster deeper engagement through pre-class preparation and in-class activities [14, 15]. Similarly, ubiquitous learning environments provide the flexibility for learning to occur anytime and anywhere, supported by advanced technologies that facilitate immediate access to resources and interactive learning experiences [13]. While existing studies highlight the effectiveness of flipped classroom models and ubiquitous learning environments, limited research focuses on their integration within medical education. Prior research in medical technology has emphasized the need for innovative approaches to bridge theoretical knowledge and practical skills [16]. For example, studies have demonstrated that technology-enhanced environments, such as augmented reality and interactive simulations, significantly improve students' clinical skills and engagement [17]. However, these studies often study flipped and ubiquitous learning as separate models without examining their combined impact. Furthermore, it investigated differences in performance based on students' varying engagement levels, a relatively unexplored area within the context of flipped classrooms and ubiquitous learning applications in medical education [18, 19]. Specifically, the study aimed to address three research questions:

1) Does the online-based flipped-ubiquitous learning approach improve students' immunology learning and laboratory performance?
2) What is the relationship between students' engagement levels and learning outcomes?
3) How do students perceive the online-based flipped-ubiquitous learning approach?

By exploring these questions, this study aimed to provide insights into the effectiveness of combining ubiquitous learning with the flipped classroom model. The findings contribute to designing flexible, high-impact learning environments for medical technology education.

II. Relevant Studies

A. Online-based Flipped Classroom in Health Science Education

The increasing integration of online platforms in education has advanced the accessibility and flexibility of learning environments. Small private online courses (SPOCs) represent a hybrid model that combines the benefits of online learning with face-to-face instruction. These courses have demonstrated their efficacy in broadening access to education and addressing high dropout rates, particularly in the initial weeks of learning [20]. SPOCs are structured to complement traditional classroom activities, providing students with access to pre-class resources such as videos and readings [21, 22]. However, their successful implementation requires strategic planning, as they still rely heavily on guided learning facilitated by instructors [20].

The flipped classroom, a blended learning approach, has become increasingly popular for enhancing active learning experiences. By engaging with core content online before class, students can actively participate in in-person activities such as problem-solving, case discussions, and reflective exercises. This model has been shown to foster positive learning outcomes and improve student engagement in various disciplines, including health sciences [3, 23, 24]. For example, in medical education, the flipped classroom has been adopted to enhance students' competencies in fields such as gynecology, pharmacology, and endocrinology. It has also been noted to improve students' motivation, communication skills, and critical thinking [2, 25, 26].

The integration of SPOCs into the flipped classroom model has opened new possibilities for innovative teaching in health sciences. Scholars have leveraged this model to facilitate case-based learning and interdisciplinary discussions, utilizing video technology and web conferencing tools to overcome geographical barriers [27, 28]. Research has highlighted the benefits of SPOC-based flipped classrooms in improving students' understanding and academic performance in physiology and radiology courses, with low-performing students showing the most significant gains [29, 30]. Moreover, laboratory-focused education, such as clinical hematology, has benefited from this approach by fostering students' confidence and practical skills [18].

Medical technology education, which trains professionals in laboratory diagnostics, traditionally relies on teacher-led sessions and supervised experiments. Although this structured format, many students struggle to fully grasp the underlying principles of laboratory methods [11]. Evidence suggests that flipped classroom strategies, particularly when integrated with SPOCs, can enhance theoretical comprehension and experimental performance in this domain. This blended approach aligns with current efforts to modernize medical technology education and optimize learning outcomes [18, 31].

Despite the demonstrated effectiveness of SPOC-based flipped classrooms, there is limited research on reforming the immunology curriculum in medical technology education. Scholars recommend integrating clinically relevant materials within the SPOC platform to enhance learning performance [19]. To address this gap, ubiquitous learning offers a compelling solution by allowing continuous access to educational resources across diverse contexts. This approach fosters deeper engagement and understanding, particularly in complex fields like immunology, where flexible, anytime-anywhere access to materials can significantly enhance learning outcomes.

B. Ubiquitous Learning Environment and Its Empirical Evidence

The ubiquitous learning environment facilitates learning anytime and anywhere, characterized by permanence, accessibility, immediacy, interactivity, and situational instructional activities. Ubiquitous computing and information technology (i.e., wireless networks, advanced computing power, long-lasting batteries, and flexible software architecture) play a critical role in supporting and accelerating this learning environment. Moreover, the ubiquitous learning environment has become an important challenge in the digital age of 21st-century teaching and learning [9]. While it is highly technology-enabled, it is not technology-driven, emphasizing the integration of technology to enhance, rather than dictate, the learning experience.

Online learning has become a widely adopted learning management system in education, evolving toward mobile learning and ubiquitous learning environments [8]. These environments offer greater mobility than traditional online learning, allowing education to take place anytime and anywhere [10, 32]. Mobile device technologies, such as barcodes, tags, and sensing, are instrumental in forming and supporting ubiquitous learning environments [10, 32] by enabling personalization, feedback requests, and recommendations [33–35]. Furthermore, online and ubiquitous learning environments provide on-demand access to relevant information during the learning process in both real-world and virtual environments. They facilitate continuous interaction among peers, teachers, and experts, making learning more dynamic and accessible across diverse settings [10, 33, 35, 36].

Ubiquitous learning environments have the potential to enhance students' learning outcomes and positively influence their perceptions, including engagement, motivation, and emotion in learning [37, 38–40]. For example, scholars integrated AR and iBeacon indoor positioning technologies into museum learning environments, which encouraged visitor interaction and reflection through a problem-based learning approach. This system promoted critical thinking and reflective learning, making museum visits more interactive and educational [41]. Researchers have explored that a technology-enhanced, interactive blended mobile museum learning environment (BMMLE - informal alternative learning) approach at history museums could enhance students' or visitors' learning outcomes through informal, alternative learning approaches [42]. The smart and ubiquitous 360-degree learning environment system in histotechnology courses using a spherical panorama imaging technique allows students and visitors to explore authentic environments, such as outdoor cultural heritage sites [43]. Similarly, a collaborative and autonomous learning environment implemented within an electrical engineering degree connected theoretical learning with laboratory work using augmented reality as a central nexus, helping students achieve their learning goals [44]. Notably, the adoption of ubiquitous learning approaches has doubled since 2014, reflecting their growing effectiveness and productivity in diverse educational contexts [45].

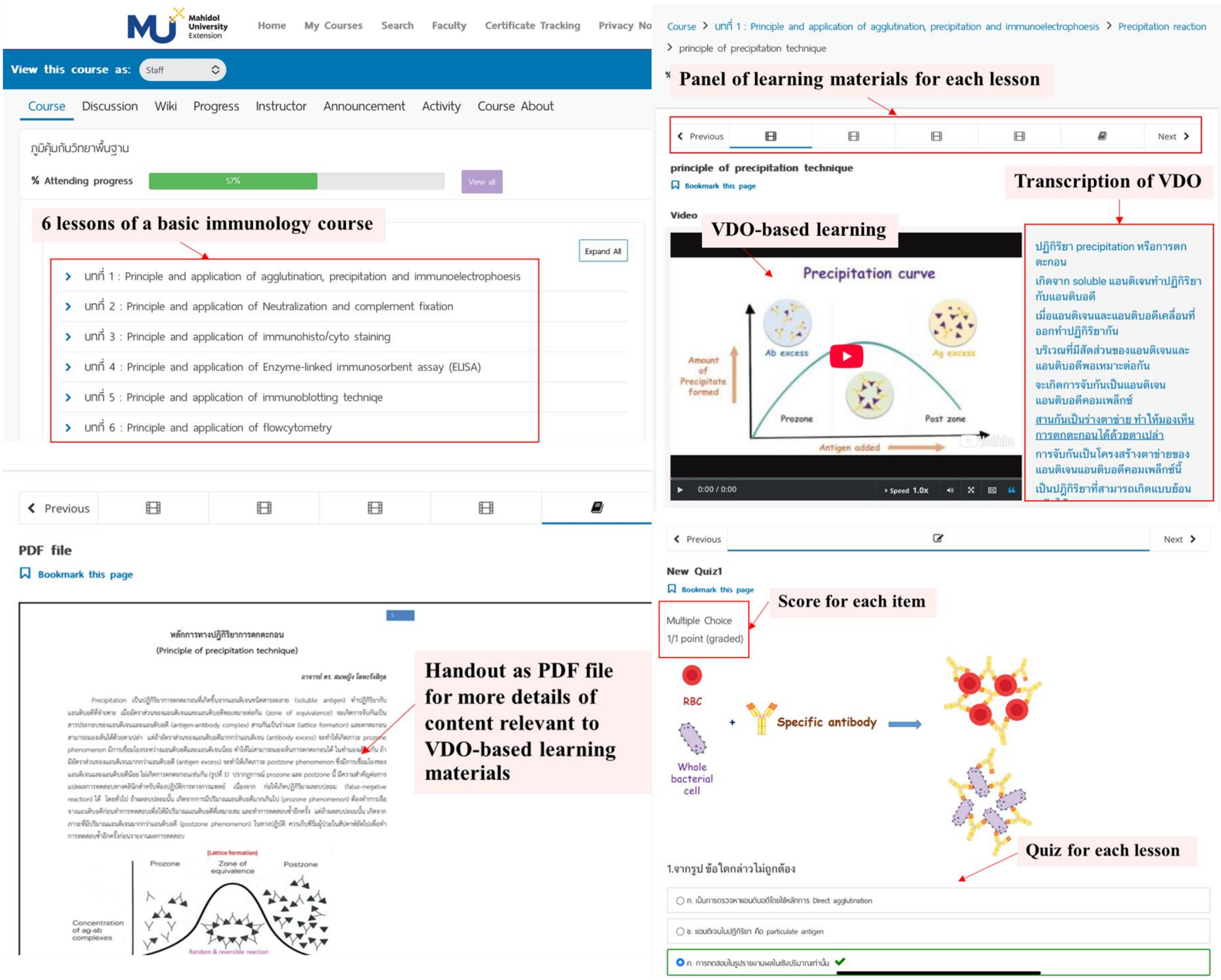

Fig. 1. The SPOC on Mahidol University extension.

The rise of ubiquitous learning environments underscores the transformative potential of technology in enabling learning anytime and anywhere, extending the possibilities of online learning into a more flexible and responsive experience. By leveraging tools such as mobile devices, interactive software, and adaptive feedback, ubiquitous learning facilitates on-demand learning that seamlessly integrates real-world and virtual interactions. Building on these advancements, integrating a flipped-classroom model within a ubiquitous learning environment presents a unique opportunity to further enrich learning experiences, especially in specialized fields like medical technology. Therefore, this study investigates the impact of an online-based flipped-ubiquitous learning approach on student outcomes in a fundamental immunology course. Specifically, it examines how varying levels of self-engagement influence learning performance and perceptions within this technology-enhanced environment.

III. Instructional Design of Online-Based Flipped-Ubiquitous Learning Approach

A Small Private Online Course (SPOC) was developed on the Mahidol University online course platform (https://mux.mahidol.ac.th), designed to enhance self-directed learning for students by serving as an alternative teaching tool with a structured and interactive knowledge framework. The course encompasses six main topics tailored for self-learning and offers comprehensive access to diverse resources through its user-friendly interface. The SPOC Course Gateway allows participants to easily navigate to the course, which is visually highlighted for accessibility. Each topic in the Courseware Section provides essential resources, including lesson plans, quizzes, and interactive materials. The learning materials include a detailed syllabus outlining the course structure and objectives, a teaching plan to guide learners, instructional videos such as infographic videos and laboratory demonstrations, laboratory protocols for practical experiences, supporting documents like teaching materials, handouts, and a discussion board to foster collaborative learning (see Fig. 1).

The SPOC curriculum was designed to align closely with the topics covered in traditional lectures, offering six core modules presented through concise and practical video lessons. Each module incorporated a pre-test, detailed learning materials, and a post-test, aiming to foster self-directed and active learning [46]. The learning materials were systematically structured into five parts: an introduction, foundational principles, materials and procedures, outcomes with interpretation, and real-world clinical applications. This comprehensive framework ensured that students could acquire the essential knowledge required for mastering basic immunological techniques (see Table 1). The SPOC also functioned as a personalized learning platform, providing flexibility for participants to progress at their speed. Learners had the option to pause videos, replay sections for better comprehension, or skip content they had already learned. To further enhance engagement, the platform featured a discussion forum where participants could ask questions and receive prompt feedback from professional course instructors, fostering a collaborative online learning environment.

Table 1. Topics covered in the SPOC of the detection of immunological reactions and applications as part of a basic immunology course

Lesson / Topic	Learning Materials
1. Agglutination, precipitation, and immunoelectrophoresis - Agglutination reaction and its application - Principle of precipitation technique - Serum protein electrophoresis and application - Immunoelectrophoresis and interpretation - Immunofixation and application in clinical used	Quizzes, Lesson plan, VDO, Laboratory protocol, handout, Discussion Broad
2. Neutralization and complement fixation - Principle and application	Quizzes, Lesson plan, VDO, handout, Teaching document, Discussion Broad
3. Immunohistochemistry and Immunocytochemistry staining - Principle, Lab demonstration, and application of immunofluorescence technique - Principle of immunoperoxidase and its application	Quizzes, Lesson plan, VDO, handout, Teaching document, Discussion Broad
4. Enzyme-linked immunosorbent assay (ELISA) - Principle and procedures - Types of ELISA and applications	Quizzes, Lesson plan, VDO, handout, Teaching document, Laboratory protocol, Discussion Broad
5. Immunoblotting technique - Principle, Lab demonstration, and application	Quizzes, Lesson plan, VDO, handout, Teaching document, Discussion Broad
6. Flow Cytometry - Principle, Lab demonstration, and application	Quizzes, Lesson plan, VDO, Laboratory protocol, handout, Discussion Broad

The instructional design of the SPOC-based flipped classroom integrates self-directed learning on the SPOC platform with interactive face-to-face teaching activities in the classroom. As shown in Fig. 2, for pre-class preparation, participants enrolled in the SPOC using their individual MU login credentials and completed a pre-test to assess baseline knowledge. Instructors provided the teaching plan one week in advance, detailing the learning objectives to guide participants' preparation. On the SPOC platform, students engaged in self-paced learning by watching infographic videos, reviewing teaching documents, and completing post-tests related to each topic.

During in-class sessions, students were divided into small groups with a 10:1 student-to-instructor ratio to facilitate focused and hands-on learning. Each group participated in laboratory activities and was assigned specific questions or topics for discussion, promoting collaborative problem-solving and critical thinking. Instructors served as facilitators, encouraging students to explore information independently while guiding as needed. The module's effectiveness was evaluated using course examinations, while a self-assessment form captured student feedback on the learning experience and perceptions of the flipped classroom approach. This blended instructional model fosters active engagement and deeper understanding by combining the flexibility of online self-learning with the interactivity of in-person teaching.

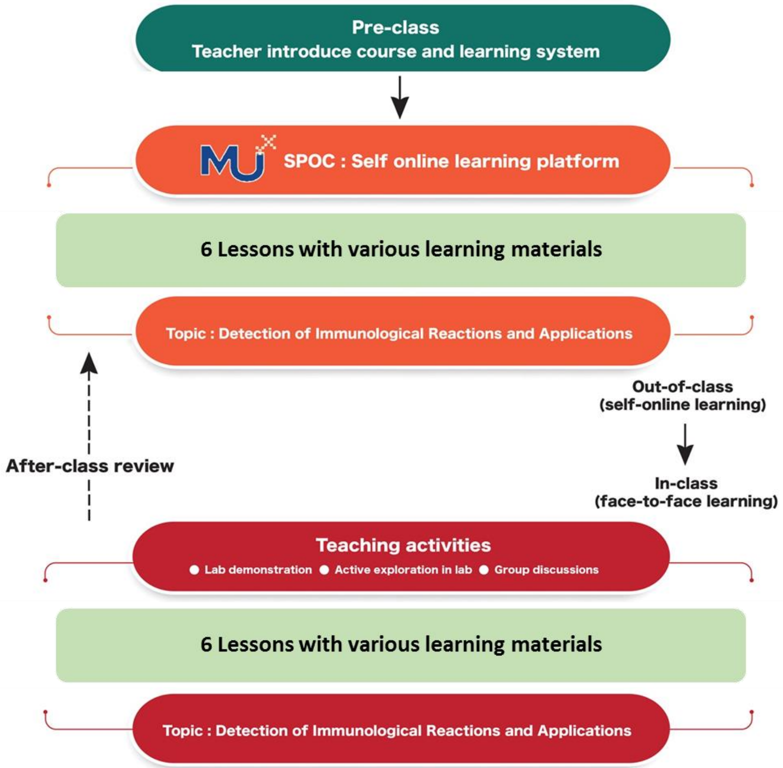

Fig. 2. Learning flow of the online-based flipped-ubiquitous learning approach.

IV. Research Methodology

A. Context and Participant Descriptions

This study was conducted at a public university in central Thailand, focusing on first-year students learning about the detection of immunological reactions and their applications in a basic immunology course. This course is part of the clinical microbiology and applied technology curriculum offered by the Faculty of Medical Technology. The university provides internet connectivity, personal computers, and mobile devices for students as needed across various learning settings. It also offers robust technological infrastructure and technical support to assist instructors in developing materials for online learning, both in-class and out-of-class activities.

The sample size for this study was determined using a purposive sampling method, which involved recruiting all 81 students enrolled in the basic immunology course at a public university in central Thailand. This approach was chosen because the study aimed to evaluate the effects of the flipped-ubiquitous learning approach within a specific cohort of medical technology students, ensuring that all participants had uniform exposure to the curriculum and learning environment. The adequacy of the sample size was supported by prior research, which indicates that a sample size of 30 or more is generally sufficient for repeated measures designs to detect significant within-subject effects [47]. With 81 participants, this study exceeds the minimum sample size requirement, providing sufficient statistical power to detect meaningful differences in performance and perceptions. Additionally, all students provided informed consent to participate, and the entire cohort was included to enhance the ecological validity of the findings by representing the full population of students in the course. This purposive sampling method aligns with the study's objectives of assessing the flipped-ubiquitous learning approach in the real-world context of an immunology course. Furthermore, all participants had prior experience using mobile devices and laptops for online learning, ensuring that the sample was well-suited for the intervention.

To ensure fairness and equal access to learning activities, students were not divided into control and experimental groups. This approach aligns with practical implementation in higher education research. All students received identical instruction from the same teacher, ensuring consistent content delivery without influencing individual outcomes. The students had the option to engage in interactive learning activities in the online-based flipped-ubiquitous learning approach, and their engagement logs were analyzed to address the research questions. Accordingly, students participated in pre-, mid-, and post-tests to evaluate their knowledge and performance at different stages of the study. Before instruction began, a 90-minute pre-test was administered to evaluate prior knowledge of detecting immunological reactions and applications. Over the next 7 weeks, students studied six lessons covering topics such as agglutination, precipitation, immunoelectrophoresis, neutralization and complement fixation, immunohistochemistry and immunocytochemistry staining, enzyme-linked immunosorbent assay (ELISA), immunoblotting technique, and flow cytometry. Learning activities were conducted within the online-based flipped-ubiquitous learning framework, allowing students to learn flexibly anytime and anywhere. A 90-minute mid-test was administered midway through the course. During the final week, students participated in face-to-face peer discussions blended with the online learning activities and received feedback from the instructor. After completing the course, a 100-minute post-test evaluated students' conceptual understanding and laboratory performance regarding immunological reactions and applications. Following the post-test, students completed a learning perception questionnaire to reflect on their experiences with the learning approach.

B. Measurement Tools

Four measurement tools (i.e., pre-, mid-, and post-conceptual understanding and laboratory performance tests and learning perception questionnaire) were implemented as the data sources to answer the research questions of this study. Moreover, logs from the online-based flipped-ubiquitous learning approach were analyzed to quantify students' interactions, serving as another key data source for the study.

1) Conceptual understanding and laboratory performance tests

The conceptual and laboratory tests were aligned with the course learning outcomes and reviewed by experienced instructors responsible for the course. The tests comprised 85 multiple-choice items and 31 open-ended questions, totaling 116 points. These assessments addressed six key topics: immunological reaction detection and applications, including agglutination, precipitation, immunoelectrophoresis, neutralization, and complement fixation, along with techniques such as immunohistochemistry, ELISA, immunoblotting, and flow cytometry. The pre-test assessed prior knowledge, while the mid- and post-tests evaluated knowledge acquisition following participation in the online-based flipped-ubiquitous learning environment.

2) Learning perception questionnaire

The immunology learning perception questionnaire was designed to assess students' perceptions following their engagement with the online ubiquitous learning system. This system incorporated case-based studies and a self-evaluation mode aimed at teaching the detection of immunological reactions and their applications. Adapted from a previously validated technology acceptance survey [48], the questionnaire was translated into Thai and included 12 items, each rated on a five-point Likert scale (1 = "strongly disagree" to 5 = "strongly agree"). The items were grouped into four dimensions, with three items per dimension: Perceived Usefulness (PU), Perceived Ease of Use (PE), Attitude (ATT), and Behavior Intention (BI). The PU dimension assessed whether students believed the system enhanced their knowledge of immunological topics. PE focused on their perceptions regarding the system's user-friendliness. ATT captured students' positive or negative experiences while participating in the case-based, self-evaluative learning activities, and BI evaluated their intention to continue using the system for other subjects. The Thai version of the questionnaire demonstrated high reliability, with a Cronbach's alpha of 0.92. Additionally, the composite reliability scores for PU, PE, ATT, and BI were 0.92, 0.80, 0.76, and 0.81, respectively, confirming the internal consistency of the instrument.

C. Experimental Procedure

This study adopted a repeated measures research design to investigate the progression of students' conceptual understanding and laboratory performance throughout the course. In the first week, students completed pre-tests assessing conceptual understanding and laboratory performance to establish their baseline knowledge before engaging in the instructional activities. Subsequently, they participated in an online-based flipped-ubiquitous learning environment. For six weeks, students engaged in asynchronous out-of-class activities, including six lessons designed with integrated self-evaluation components. Their interactions within this online environment were logged for subsequent data analysis. At the conclusion of week 6, students took mid-term tests to measure changes in their conceptual understanding and laboratory performance resulting from the out-of-class learning activities.

Beginning in week 7, students transitioned to face-to-face, in-class activities integrated with the online-based flipped-ubiquitous learning platform. This phase, which also spanned six weeks, incorporated laboratory demonstrations, hands-on exploration, and collaborative discussions centered on immunological reaction detection and applications. At the end of week 12, students completed post-tests on conceptual understanding and laboratory performance, responded to a learning perception questionnaire, and provided qualitative feedback on their experiences throughout the course.

D. Data Analysis

Quantitative data analysis was performed using SPSS statistical software. The collected data was cleaned prior to analysis. 15 students who missed portions of the learning activities were excluded, leaving 66 complete datasets for analysis to address the research questions in this study. The total score for the pre-, mid-, and post-tests were standardized to 100 points. For RQ1, the mean difference from the students' pre- to mid- and post-test results was computed by a one-way repeated measure ANOVA test. Regarding RQ2, a correlation test was performed to investigate the relationship between students' frequency of interactions in the self-evaluation mode and their improvements in conceptual understanding and laboratory performance. Students were further categorized into two groups (i.e., high and low engagement) based on their frequency of interaction within the out-of-class online-based flipped-ubiquitous learning environment. A two-way repeated measures ANOVA was computed to determine significant differences in conceptual understanding and laboratory performance between the two groups. Regarding RQ3, descriptive statistical analysis was conducted on the Likert-scaled questionnaire data, calculating means and standard deviations for each item. Additionally, a Chi-square test was used to compare the distribution of student responses (on a 1 to 5 scale) between two groups, further assessing the impact of the online-based flipped-ubiquitous learning environment on learning perceptions.

V. RESULTS

A. Analysis of Learning Performance Improvement

To address RQ1, the main effects of the online-based flipped-ubiquitous learning environment were analyzed using a one-way repeated measures ANOVA on students' conceptual understanding and laboratory performance scores across the pre-, mid-, and post-tests. As shown in Table 2, significant improvements were observed in the scores over time. Pairwise comparisons with post hoc tests using the Bonferroni correction revealed statistically significant differences between pre- and mid-scores and between pre-and post-test scores ($p < 0.05$). However, the slight decrease in scores from the mid- to post-test was not statistically significant ($p > 0.05$). These results suggest that the six-week online-based flipped-ubiquitous learning environment elicited a statistically significant improvement in students' understanding of the detection of immunological reactions and applications. However, the additional one week of face-to-face in-class learning activities blended with the online-based flipped-ubiquitous learning environment did not result in a statistically significant improvement on the topic.

Table 2. Differences across pre-, mid-, and post-tests

Test	M	SD	$F_{(1,65)}$	η^2	Pairwise comparison
Pre	60.97	14.62			Mid > Pre
Mid	70.81	14.57	11.634*	0.981	Post > Pre
Post	69.28	12.92			

*$p < 0.05$

B. Analysis of Learning Performance between Higher- and Lower-engagement Students

The frequency of students' interactions with the online-based flipped-ubiquitous learning environment was positively and significantly correlated with their mid- and post-test conceptual understanding and laboratory performance scores. The Pearson Correlation values were $r = 0.443$, $p = 0.000$, and $r = 0.361$, $p = 0.003$, respectively, as shown in Table 3.

To analyze the relationships between students' engagement levels in the online-based flipped-ubiquitous learning environment, students were categorized into two groups based on their frequency of using the system. The average frequency was 5.43. Students with a frequency greater than 5.00 were classified as the higher-engagement group, while those with a frequency of 5.00 or less were classified as the lower-engagement group. An independent samples t-test was performed to ensure the learning performance between the two groups before participating in the online-based flipped-ubiquitous learning environment. Subsequently, the pre-, mid-, and post-test scores for conceptual understanding and laboratory performance were analyzed using a two-way repeated measures ANOVA.

Table 3. Correlations between students' engagement and tests (N = 66)

	Engagement	Mid- conceptual understanding and laboratory performance test	Post-conceptual understanding and laboratory performance test
Engagement	1	0.443**	0.361**
Mid- conceptual understanding and laboratory performance test	0.443**	1	0.576**
Post-conceptual understanding and laboratory performance test	0.361**	0.576**	1

** Correlation is significant at the 0.01 level

The independent samples *t*-test revealed no statistically significant difference in the pre-test scores for conceptual understanding and laboratory performance between higher-engagement students ($M = 60.77$, $SD = 13.53$) and lower-engagement students ($M = 61.23$, $SD = 16.14$), $t(64) = 0.126$, $p > 0.05$), as shown in Table 4. This result indicates that the two groups were comparable in their conceptual understanding and laboratory performance on the topic of detecting immunological reactions and applications before participating in this study.

Table 4. Results of the *t*-test for the two groups

Measures	Higher-engagement			Lower-engagement			*T*-score
	N	M	SD	N	M	SD	
Pre-test	37	60.77	13.53	29	61.23	16.14	0.126
Mid-test	37	75.26	12.85	29	65.13	14.87	2.967*
Post-test	37	72.63	10.72	29	65.00	14.36	2.389*

*$p < 0.05$

A two-way repeated measures ANOVA was conducted to determine whether the two groups (higher- and lower-engagement) significantly improved their score on the conceptual understanding and laboratory performance test from the pre- to the mid and post-test, as shown in Fig 3. Students' scores significantly increased on the conceptual understanding and laboratory performance mid-test (higher-engagement: $M = 75.26$, $SD = 12.85$, lower-engagement: $M = 65.13$, $SD = 14.87$) and post-test (higher-engagement: $M = 72.63$, $SD = 10.72$, lower-engagement: $M = 65.00$, $SD = 14.36$) as compared to the pre-test ($F_{(2, 56)} = 12.021$, $p < 0.05$), as shown in Table 4. These results indicate that participation in the online-based flipped-ubiquitous learning environment significantly improved both groups' conceptual understanding and laboratory performance in detecting immunological reactions and applications. However, no significant difference was observed between mid- and post-test scores, as scores slightly decreased. When comparing post-test scores, a significant difference was observed between the two groups ($t(64) = 2.389$, $p < 0.05$), as shown in Table 3. The two-way repeated measures ANOVA also confirmed a significant difference between the groups when averaging mid- and post-test scores ($F_{(1, 28)} = 5.917$, $p < 0.05$), as shown in Table 4. These results suggest that higher-engagement students achieved greater conceptual understanding and laboratory performance than lower-engagement students in the online-based flipped-ubiquitous learning environment.

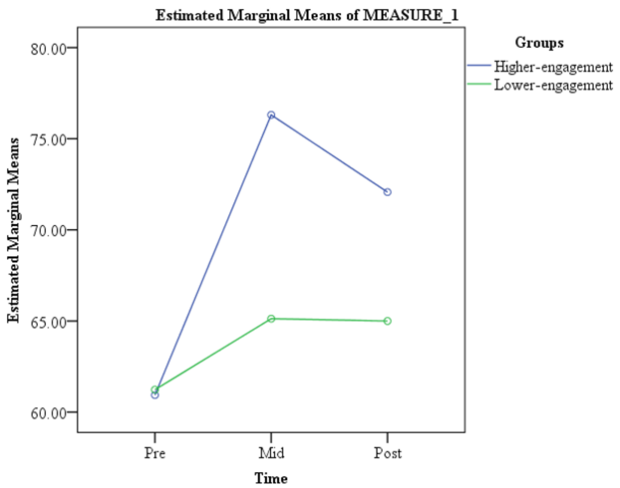

Fig. 3. Plots of the three times and the two groups for a two-way repeated measures ANOVA.

Table 5. Results of two-way repeated measures ANOVA for the two groups

		Two-way repeated measures ANOVA	
		F	*p*-value
Group	High-engagement student *vs*. Low-engagement student	5.917	0.022*
Time	Post *vs*. mid *vs*. pre	12.021	0.000*
Time × Group	All six groups	2.929	0.073
Group	High-engagement student *vs*. Low-engagement student	4.053	0.054
Time	Mid *vs*. pre	16.172	0.000*
Time × Group	All four groups	4.478	0.043*

*$p < 0.05$

It is important to note that the two groups showed no significant overall increase in their conceptual understanding and laboratory performance scores across the pre-, mid-, and post-tests ($F_{(2, 56)} = 2.929$, $p > 0.05$), as shown in Table 5. However, higher-engaged students demonstrated a significant increase in their scores between the pre- and mid-tests, as illustrated in Fig. 3. This was further confirmed by the two-way repeated measures ANOVA, which showed a significant difference in gains for higher-engaged students between the pre- and mid-test scores ($F_{(1, 28)} = 4.478$, $p < 0.05$), as shown in Table 5.

C. *Analysis of Learning Perceptions*

The questionnaire data was collected to address RQ3. Students were asked to respond to a questionnaire to assess their perceptions of usefulness, ease of use, attitude, and behavioral intention associated with the online-based flipped-ubiquitous learning environment. Descriptive statistics were used to summarize results, as shown in Table 6. Students expressed their perceptions of learning activities in the online-based flipped-ubiquitous learning environment, especially the self-evaluation mode, which measured their understanding and provided feedback to improve their learning and laboratory performance on detecting immunological reactions and applications. The mean scores for the 12 questionnaire items were close to 4.00 of 5.00, indicating general agreement with the effectiveness of the self-evaluation mode. Notably, more than 50% of the students reported a positive attitude and expressed a willingness to continue participating in the online-based flipped-ubiquitous learning environment. Additionally, over 70% of the students reflected that the learning activities were useful for supporting their conceptual understanding and laboratory performance. They also found the instructions easy to follow, enabling them to construct their knowledge effectively.

Table 6. Students learning perceptions of the online-based flipped-ubiquitous learning environment ($N = 66$)

Item	Min	Max	M	SD	Percentage (>4)
PU1: Participating in an online-based flipped-ubiquitous learning environment can enhance my learning of immunology techniques.	2	5	4.09	0.74	80.30
PU2: Learning through an online-based flipped-ubiquitous learning environment can improve my learning efficiency in immunology techniques.	2	5	4.03	0.72	78.80
PU3: Learning through an online-based flipped-ubiquitous learning environment can increase the quality of outcomes from my learning in immunology techniques.	2	5	3.97	0.68	78.80
PEU1: The steps in the online-based flipped-ubiquitous learning activities are clear.	3	5	3.97	0.70	74.20
PEU2: The online-based flipped-ubiquitous learning environment aligns with the learning goals of my study on immunology techniques.	3	5	3.95	0.69	74.20
PEU3: The steps in the online-based flipped-ubiquitous learning environment helped me easily access the content on immunology techniques.	3	5	4.11	0.64	84.90
ATT1: The online-based flipped-ubiquitous learning environment makes learning about immunology techniques more interesting.	2	5	3.83	0.85	63.60
ATT2: The online-based flipped-ubiquitous learning environment makes me feel excited to learn about immunology techniques.	2	5	3.57	0.79	48.40
ATT3: The online-based flipped-ubiquitous learning environment is suitable as a tool for learning about immunology techniques.	2	5	3.93	0.74	75.70
BI1: I will participate in other courses that use an online-based flipped-ubiquitous learning approach in my future studies.	2	5	3.79	0.75	68.20
BI2: I think I would frequently participate in other courses that use an online-based flipped-ubiquitous learning approach.	2	5	3.71	0.76	59.10
BI3: I would recommend the online-based flipped-ubiquitous learning approach to others for learning about immunology techniques.	2	5	3.74	0.79	68.10

Additionally, in addressing RQ3, the Chi-square test was used to examine the positive perceptions of integrating self-evaluation mode into the online-based flipped-ubiquitous learning environment between higher- and lower-engagement student groups. The results indicated that in 1 of the 4 perception dimensions compared, higher-engagement students were significantly more likely to show a positive attitude, with a higher percentage of rating above 4, compared to lower-engagement students, as shown in Table 7, for the remaining 3 perception dimensions, higher-engagement and lower-engagement students displayed similar rating patterns, with scores ranging from 2 to 5.

Table 7. Scale distribution comparisons between the higher-engagement group and lower-engagement group (in parenthesis: Lower-engagement group)

Dimension	Item	Scale 1	2	3	4	5	Chi-square test
Perceived usefulness (PU)	PU1	0 (0)	1 (0)	8 (4)	17 (16)	11 (9)	0.655
	PU2	0 (0)	1 (0)	8 (5)	17 (18)	11 (6)	0.512
	PU3	0 (0)	1 (0)	8 (5)	20 (19)	8 (5)	0.691
Perceived ease of use (PEU)	PEU1	0 (0)	0 (0)	10 (7)	20 (14)	7 (8)	0.706
	PEU2	0 (0)	0 (0)	8 (9)	20 (15)	9 (5)	0.619
	PEU3	0 (0)	0 (0)	5 (5)	19 (20)	13 (4)	0.144
Attitude (ATT)	ATT1	0 (0)	2 (1)	10 (11)	15 (11)	10 (6)	0.791
	ATT2	0 (0)	2 (1)	12 (19)	18 (5)	5 (4)	0.036*
	ATT3	0 (0)	2 (0)	7 (7)	22 (14)	6 (8)	0.371
Behavioural intention (BI)	BI1	0 (0)	2 (1)	12 (6)	17 (18)	6 (4)	0.611
	BI2	0 (0)	1 (1)	14 (11)	15 (14)	7 (3)	0.792
	BI3	0 (0)	2 (3)	10 (6)	19 (17)	6 (3)	0.715

*$p < 0.05$

VI. Discussions and Conclusions

This study implemented an online-based flipped-ubiquitous learning approach in an immunology classroom to enhance university students' knowledge in the detection of immunological reactions and applications, evaluate their learning perceptions, and explore correlations within the proposed learning framework. The findings revealed three positive outcomes corresponding to each research question. These results contribute to the originality of the approach and provide a valuable reference for designing effective learning environments in basic immunology courses, particularly for teaching the detection of immunological reactions and applications.

A. Addressing RQ1: Enhancing Understanding and Laboratory Performance

The findings indicate that the online-based flipped-ubiquitous learning approach significantly enhanced students' understanding and laboratory performance in immunology for the study. Statistically significant improvements were observed between the pre-, mid-, and post-test stages, highlighting a clear progression in students' ability to perform immunological reactions and applications. This finding suggests that combining online-based flipped learning with ubiquitous access, which allows flexible, anytime-anywhere learning, fosters sustained engagement and comprehension, leading to measurable learning gains. While a slight decline was observed from mid- to post-test scores, it was not statistically significant, indicating that most initial gains were retained. These results highlight the potential of a sustained flipped-ubiquitous model in maintaining performance improvements in complex topics. The findings also support blended learning theories, suggesting that integrating Small Private Online Courses (SPOCs) with face-to-face in-class learning enables deeper exploration of course content [19]. The SPOC's design likely contributed to these results, providing flexible and responsive learning pathways tailored to students' needs [20, 49]. Particularly effective were the SPOC's online videos, which served as a ubiquitous learning resource, provided through the likely augmented student learning, as reflected in the mid- and post-test scores. This result may be attributed to the SPOC's design, which specifically catered to the needs of the students, providing adaptable and responsive learning pathways. Especially impactful were the SPOC's online videos, a ubiquitous learning resource, allowing students to engage with the material beyond traditional classroom boundaries [50]. Face-to-face in-class activities, including laboratory demonstrations, hands-on exploration, and group discussions, further reinforced foundational knowledge acquired through the SPOC. These in-class interactions enabled students to apply SPOC-acquired knowledge to laboratory tasks, solidifying their understanding of immunological concepts. This structured pedagogical approach aligns with the ubiquitous learning principles, where learning is continuous and contextually adaptive [13, 51]. The foundation provided by the SPOC allowed face-to-face in-class activities to deepen students' conceptual and practical understanding of immunology, mirroring results from similar studies involving SPOC-based flipped courses in medical disciplines such as physiology and histopathology [29, 52, 53].

B. Addressing RQ2: Engagement and Learning Outcomes

The findings revealed a significant positive relationship between students' engagement levels in the online-based flipped-ubiquitous learning environment and their learning outcomes in immunology. Pearson correlation values indicated that higher interaction frequency with the learning platform correlated with improved conceptual understanding and laboratory performance, as demonstrated by mid- and post-test scores. These findings align with prior studies emphasizing the role of engagement in enhancing outcomes in blended and online learning environments [54]. Comparisons between higher- and lower-engagement groups confirmed that both groups displayed improvement from pre- to mid- and post-tests; however, higher-engagement students consistently outperformed their lower-engagement peers. For example, mid-test scores for the higher-engagement group (M = 75.26) were significantly higher than those of the lower-engagement group (M = 65.13), and a similar trend was observed for post-test scores (higher M = 72.63 *vs.* lower M = 65.00). The two-way repeated measures ANOVA further corroborated these differences, demonstrating that engagement levels were critical for maximizing learning gains. These findings are consistent with existing research on the flipped classroom model, which demonstrates that active engagement with course materials, both online and in-class, enhances student learning. For instance, previous studies have shown that students who actively engage in pre-class activities in a flipped classroom achieve better learning outcomes compared to those with lower engagement levels [7]. Interestingly, while both engagement groups showed a slight decrease in scores from the mid- to post-test, this change was not statistically significant, suggesting that the initial performance gains were largely stable. It underscores the importance of sustained engagement throughout the course, as it supports students' ability to retain and apply complex knowledge. High-engagement students were particularly able to leverage the flexibility and accessibility of the ubiquitous learning resources, allowing them to engage with material at their own pace and according to their specific needs. This personalized approach likely facilitates deeper learning and better retention of course content. Ubiquitous learning environments, which provide opportunities to learn anytime and anywhere, empower students by enabling them to revisit content and apply knowledge in varied contexts. This adaptability significantly enhances their ability to retain and utilize knowledge effectively [13]. These findings highlight that while the online-based flipped-ubiquitous approach improves learning outcomes for all students, the level of engagement plays a pivotal role in maximizing these benefits. Higher engagement enables students to take full advantage of the platform's resources and active learning opportunities, thereby enhancing their conceptual understanding and practical laboratory skills. It aligns with the concept that ubiquitous learning environments provide unique affordances for personalized and sustained engagement, which are critical for mastering complex subject matter. Engagement in a ubiquitous learning environment fosters a deeper connection to the material, leading to improved learning performance and greater student satisfaction. Additionally, the positive relationship between engagement and learning outcomes observed in this study reinforces findings from various educational contexts, which suggest that frequent interaction with course materials, particularly in a flipped and ubiquitous environment, enhances performance and academic achievement [36].

C. Addressing RQ3: Student Perceptions of the Learning Environment

The findings from this study demonstrate that the online-based flipped-ubiquitous learning environment significantly enhanced students' perceptions of their learning experiences. It aligns with evidence supporting the efficacy of such pedagogical approaches in higher education, where students reported positive attitudes and greater appreciation for reformed teaching methods [21, 55]. Notably, the integration of practical and meaningful activities within the SPOC and in-class sessions increased students' interest and enjoyment while simultaneously reducing anxiety. It suggests that the flipped-ubiquitous learning model effectively facilitated students' understanding and application of immunology concepts. Although this approach may not universally suit all disciplines, its effectiveness in fostering comprehension and problem-solving in immunological reactions is noteworthy. The structured content delivered through the SPOC platform was instrumental in boosting learning outcomes, fostering active participation, and enhancing the enjoyment of in-class activities [56]. By offering diverse learning materials and personalized strategies, this model empowered students to learn at their own pace—an essential factor shaping their attitudes and perceptions [57]. Additionally, teachers utilized out-of-class time to address students' queries through online forums and communication tools, enabling in-class sessions to focus on guiding students' development of higher-order thinking skills.

These results align with prior studies demonstrating the positive influence of blended and flipped learning environments on cognitive and affective domains, including knowledge acquisition, comprehension, and skill development [24]. For instance, the success of this approach mirrors findings in clinical hematology laboratory teaching [18] and basic medical laboratory courses employing blended methodologies [54].

However, several considerations arose in implementing this approach for the first time in a university-level immunology course. First, many Thai students are unfamiliar with self-directed online learning. This challenge was addressed by integrating interactive and diverse materials into the SPOC platform to support active learning effectively. Second, the variability in students' foundational knowledge posed challenges in delivering complex immunology content. It was mitigated through instructional videos designed with a simple and practical approach, providing clear, step-by-step guidance on test procedures, result interpretation, and clinical applications. Lastly, cultural factors, such as hesitancy to ask questions in class, were addressed by organizing small-group activities during face-to-face sessions (with a 10:1 student-to-lecturer ratio), which encouraged active engagement and problem-solving. This strategy aligns with successful applications of team-based learning in other medical education contexts, such as dermatology and venereology studies [58]. Combining technologies like SPOC with flipped-ubiquitous classrooms offers a synergistic approach to enhancing learning outcomes. This study contributes a valuable reference for adapting similar strategies in medical technology education. Future research should expand the application of this pedagogical model to other courses, including larger class sizes, to validate these findings and explore comparative effectiveness with alternative teaching methods.

D. Practical Implications

The study demonstrated that an online-based flipped-ubiquitous learning approach significantly enhances students' conceptual understanding and laboratory performance, highlighting the potential of technology-enabled environments to engage learners actively. Such models are particularly valuable for subjects requiring both theoretical knowledge and practical application. Educational institutions should adopt these approaches to complement traditional methods and foster self-directed learning. The notable performance improvements among higher-engagement students emphasize the need for strategies encouraging active participation across all learners. Policy guidelines should support adaptive learning systems, personalized feedback, and collaborative tools to ensure equitable opportunities and address diverse learner needs. Flexible access to learning materials anytime and anywhere aligns with the increasing demand for adaptable education, especially in medical technology, where students balance rigorous schedules. Students' positive perceptions of the flipped-ubiquitous learning environment underscore its effectiveness in enhancing motivation and reducing learning anxiety. Incorporating blended models could create interactive, student-centered experiences that improve learning outcomes and satisfaction. While the study focuses on immunology education, the model is adaptable to other disciplines, particularly those involving laboratory-based learning. Interdisciplinary collaboration and access to educator training can refine and implement these models effectively across diverse fields. This study provides empirical evidence supporting the efficacy of blended learning approaches in higher education. Policymakers should leverage these findings to advocate for curriculum reforms integrating flipped and ubiquitous methodologies. Such reforms can modernize educational practices, align them with 21st-century learning needs, and equip students with essential skills for rapidly evolving professional fields. By scaling best practices, institutions can foster more engaged, motivated, and adaptable learners.

E. Limitations and Future Work

This study introduced the approach in a basic immunology course, confirming its effectiveness in promoting student learning and positively influencing their perceptions of basic immunology. However, the study has certain limitations that should be addressed in future research. First, the sample size consisted of 66 participants, representing the total enrollment in the course. While this sample size meets the recommended threshold for repeated measures designs, it is relatively small and specific to a single cohort. It may limit the generalizability of the findings to broader student populations or different educational contexts. Future studies should involve larger and more diverse samples to validate these findings and expand their applicability across various educational settings. Additionally, further development is needed to refine the online-based flipped-ubiquitous learning approach, particularly to enhance its adaptability and scalability in other courses and disciplines. Long-term teaching practices are essential to verify its sustained effectiveness and impact. This innovative study provides a fresh perspective for curriculum reform in medical technology education and holds the potential to bring about a qualitative leap in the future of this field.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

SL conducted, analyzed, investigated the research and originally drafted the manuscript; KE investigated the research and created the figure; PP conceptualized, proposed methodologies, reviewed and edited the manuscript; NK reviewed and edited the manuscript. All authors had approved the final version.

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