The Application and Effectiveness of Microlearning in Flipped Classroom

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Abstract – **This study discusses the application and effect of micro-learning in flipped classroom. Through theoretical analysis and empirical research, it reveals the significant role of micro-learning resources in improving students' learning effectiveness, satisfaction and participation. The research shows that the fragmented and modular features of micro-learning are highly compatible with the autonomous learning needs of flipped classroom, which can effectively reduce the cognitive load of students and promote the deep internalization of knowledge. In terms of application design, the development and integration of micro-learning resources, the design of pre-class learning activities and the optimization of classroom activities are the key links of successful implementation. The effect evaluation shows that micro-learning not only significantly improves students' academic performance, but also enhances students' learning motivation and engagement through multi-modal interaction and gamification elements. However, the study also points out that micro-learning still faces challenges in resource development, student adaptability and teacher role transformation. Future studies should further explore the applicability of micro-learning in different disciplines and education stages, and strengthen technical support and teacher professional development to promote the continuous optimization and innovation of flipped classroom.**

Keywords – **Flipped classroom; Learning effectiveness; Participation; Teaching design; Cognitive load; Educational technology**

I. INTRODUCTION

With the rapid development of information technology, the education model is undergoing profound changes. Flipped classroom, as an innovative teaching method, provides students with more opportunities for active learning and deep thinking by reconstructing the sequence of knowledge transfer and internalization. However, the successful implementation of flipped classroom cannot be separated from the support of efficient learning resources, and micro-learning, with its fragmented, modular and interactive characteristics, has become an ideal complement to flipped classroom. Micro-learning not only helps students master basic knowledge efficiently before class, but also enhances learning motivation and engagement through multi-modal presentation and instant feedback mechanism. This study aims to explore the application design and effect evaluation of micro-learning in flipped classroom, and reveal its potential and challenges in improving learning effectiveness and optimizing teaching process through theoretical analysis and empirical research. The research questions focus on how micro-learning resources are integrated with flipped classroom instructional design, and their specific effects on students' learning behaviour and teachers' teaching practice. This study not only provides practical guidance for educators, but also provides theoretical basis for the deep integration and innovation of educational technology in the future.

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II. Theoretical basis of micro-learning and flipped classroom

The concept and characteristics of micro-learning

As an innovative paradigm in the field of educational technology, the core of micro-learning is to reconstruct the knowledge transfer path through short-term, focused and highly modular learning units, so as to adapt to learners' cognitive habits and information processing modes in the digital age. From the time dimension, micro-learning usually cuts content into independent fragments of 5 to 15 minutes. This design not only fits the decay curve of human attention cycle, but also significantly improves the efficiency of knowledge absorption by reducing the single cognitive load (Redondo et al., 2020). However, its value is far more than time compression. In terms of content structure, micro-learning emphasizes the atomization of knowledge points, that is, by eliminating redundant information extraction, each micro-unit focuses on a single concept or skill. This "minimum feasible knowledge unit" construction strategy not only avoids the risk of information overload of traditional linear courses, but also avoids the risk of information overload. It also provides learners with the possibility of flexible knowledge reorganization. It is worth noting that the characteristics of micro-learning are not only reflected in its formal fragmentation, but also in its inherent interconnection and situational adaptability: on the one hand, with the help of hypertext links and intelligent recommendation algorithms, scattered micro-units can be dynamically integrated into personalized learning paths (such as SCORM standard based learning management system); On the other hand, micro-learning resources are often embedded with short videos, interactive quizzes or gamification elements to enhance the immersion experience of learners through multi-modal stimulation, which is particularly prominent in mobile-first learning scenarios. Further analysis shows that the essential characteristics of micro-learning can be summarized as three dialectical unity: First, a dynamic balance is built between "fragmentation" and "systematization", that is, through metadata labeling and knowledge graph technology, discrete micro-content forms a logical and coherent macro cognitive framework; Second, the tension between "standardization" and "personalization"

is realized, such as the dynamic content adaptation mechanism based on learning analysis; Third, the synergistic effect between "immediacy" and "long-acting" is sought, which not only meets the demand of instant learning in fragmented time, but also promotes long-term memory consolidation through interval repetition algorithm. This multi-dimensional feature system makes micro-learning not only an effective tool to cope with cognitive challenges in the age of information explosion, but also restructures the relationship between knowledge authority and learners' subjectivity on a deep level - learners transform from passive receivers to "curators" who can independently schedule learning rhythm and choose cognitive paths. It is worth noting that the theoretical foundation of micro-learning does not exist in isolation, but resonates with constructivism learning theory and distributed cognition theory: the former emphasizes that learners complete meaning construction through active exploration in micro-units, while the latter realizes social distribution of cognitive tasks through technological intermediaries.

Flipped classroom teaching mode

As an innovative mode that subverts the traditional teaching timing, flipped classroom's core concept is to achieve the dual improvement of teaching efficiency and learning depth through the spatiotemporal reconstruction of "knowledge transfer" and "knowledge internalization" (Muhisn et al., 2020). Specifically, flipped classroom preplaces knowledge teaching in traditional classrooms before class, and students learn independently by watching teaching videos, reading digital materials or completing online tasks. Classroom time is reassigned to higher-order cognitive activities such as teacher-student interaction, group collaboration, and problem solving. The theoretical basis of this teaching model can be traced back to the constructivism learning theory, which emphasizes that learners complete the meaning construction of knowledge through active participation and social interaction, while flipped classroom provides students with more opportunities for practice and reflection through the reconfiguration of classroom time. In addition, flipped classrooms are heavily influenced by mastery learning theory, which ensures that each student has the basics before entering the classroom through the design of a personalized learning path, thus laying the foundation for deep learning in the classroom. However, the successful implementation of flipped classroom depends not only on the adjustment of timing, but also on the systematic optimization of teaching design: In the pre-class stage, teachers need to carefully design learning resources and tasks to ensure that they can not only stimulate students' autonomous learning motivation, but also provide necessary knowledge reserves for classroom activities. At the classroom level, teachers need to change from "knowledge providers" to "learning facilitators" to promote the development of higher order thinki'g by designing problem situations, organizing discussions, and providing immediate feedback. It is worth noting that flipped classroom is not a static teaching template, and its specific implementation forms can be diversified according to the characteristics of disciplines, student groups and technical conditions. For example, in STEM (science, technology, engineering, and math) fields, flipped classrooms are often combined with project-based learning to enhance students' practical skills through real-world problem solving. In the humanities, flipped classrooms tend to foster critical thinking through debate and case studies. Although flipped classroom has significant advantages in theory, its practical effect is still restricted by many factors, such as students' autonomous learning ability, teachers' instructional design level, and the adequacy of technical support.

The convergence of micro-learning and flipped classroom

The deep integration of micro-learning and flipped classroom is not accidental, but based on their highly complementary and synergistic effects in terms of teaching objectives, learning process and technology application (Rincon-Flores et al., 2024). From the perspective of teaching objectives, flipped classroom aims to realize the internalization and transfer of knowledge through self-learning before class and deep interaction in class, while micro-learning provides an efficient path to realize this goal through short, focused learning units. The fragmented features of micro-learning are highly in line with the pre-class learning needs of flipped classroom: students can use the fragmented time to complete the preliminary mastery of basic knowledge through micro-learning resources such as micro-videos, interactive quizzes or knowledge cards, thus freeing up more time for higher-order cognitive activities in class. The modular design of micro-learning enables the learning content to be flexibly combined according to the individual differences of students, which not only meets the needs of personalized learning in flipped classroom, but also helps students adjust learning strategies in time through instant feedback mechanism, thus improving learning efficiency. From the perspective of learning process, the combination of micro-learning and flipped classroom shows unique advantages under the dual framework of cognitive load theory and constructivism learning theory: micro-learning can effectively reduce the external cognitive load of students by breaking down complex knowledge into small units that are easy to digest, so that students can devote more cognitive resources to problem-solving and knowledge construction in class. At the same time, through social interaction and collaborative learning, flipped classroom provides students with the opportunity to integrate the knowledge fragments acquired in micro-learning into a systematic cognitive structure, thus realizing the transition from "fragmented learning" to "holistic understanding". From the perspective of technology application, the digital features of micro-learning resources form a natural synergistic relationship with the technological dependence of flipped classroom. Based on the learning management system (LMS) or mobile learning platform, teachers can track students' micro-learning progress and effect in real time, and dynamically adjust the design of classroom activities according to the data analysis results. Students can access micro-learning resources through multiple terminals to achieve a seamless blended learning experience. This technology-driven instructional optimization not only

improves the efficiency of flipped classroom implementation, but also provides educators with more possibilities for innovative instructional design. The convergence of micro-learning and flipped classroom is not only reflected in the form of complementarity, but also in the common direction of learner-centered education paradigm transformation, which provides theoretical and practical enlightenment for the deep integration of modern educational technology.

III. Application design of micro-learning in flipped classroom

Development and integration of micro-learning resources

The development and integration of micro-learning resources is the core premise for their effective application in flipped classroom. This process not only involves the production of resources at the technical level, but also requires the organic unity of content, form and learning objectives under the guidance of instructional design theories (Arnab et al., 2021). In terms of content design, micro-learning resources should follow the principle of "less and better", that is, each micro-unit should focus on a single knowledge point or skill point to avoid information overload. For example, in a mathematics course, a micro-learning unit could be dedicated to "the properties of quadratic function images" and help students intuitively understand abstract concepts by dynamically demonstrating the effects of parameter changes on images through visual tools. In terms of formal design, micro-learning resources should make full use of the advantages of multimedia technology to enhance learners' participation and immersion through multi-modal presentation such as short videos, animations, interactive tests or gamification elements. For example, in language learning, micro-learning resources can be combined with speech recognition technology to provide students with instant pronunciation feedback, thereby strengthening the automated formation of language skills. However, the design of micro-learning resources should not be carried out in isolation, but should be closely connected with the overall teaching design of flipped classroom. In the pre-class stage, micro-learning resources should serve as the core carrier of students' autonomous learning, and help students to effectively master basic knowledge by guiding them with clear learning goals and tasks. In the classroom stage, micro-learning resources can be used as auxiliary tools for teachers to carry out in-depth teaching activities, such as providing knowledge anchors for class discussion or problem solving by quickly reviewing key concepts in micro-videos. The integration of micro-learning resources also needs to rely on the learning management system (LMS) or mobile learning platform, and realize the dynamic management and personalized push of resources through technical means. For example, based on learning analysis technology, the system can automatically recommend micro-learning resources suitable for students' current learning level according to their learning behaviour data, so as to achieve precise learning support. It is worth noting that the development and integration of micro-learning resources also needs to consider cross-platform compatibility and accessibility to ensure that students can seamlessly access learning content on different devices. For example, responsive design techniques enable micro-learning resources to adapt to different screen sizes, improving the convenience of mobile learning. Finally, the development and integration of micro-learning resources should also pay attention to openness and sharing, for example, by following the Open Educational resources (OER) standard, to promote the reuse and optimization of micro-learning resources in different educational scenarios. The development and integration of micro-learning resources is not only the process of technology realization, but also the deep integration of educational concept and teaching design, and its successful implementation will provide strong support for the improvement of flipped classroom teaching effect.

Design of pre-class learning activities

As the cornerstone of flipped classroom, the design quality of pre-class learning activities directly determines the depth and effect of higher-order cognitive activities in the classroom, while the introduction of micro-learning has injected new vitality and possibility into this part. In terms of goal setting, pre-class learning activities should clearly distinguish between the mastery of basic knowledge and the initial stimulation of higher-order thinking, and the design of micro-learning resources should focus on this dual goal. For example, in science courses, students can learn about basic concepts (such as Newton's laws of motion) by watching microvideos, then completing interactive quizzes to test understanding and passing open-ended questions (such as "How do you explain inertial phenomena in everyday life?"). Stimulate initial thinking. In task design, pre-class learning activities should focus on the stratification and progression of tasks to meet the needs of different learners. For example, teachers can design two types of activities: "core tasks" and "extended tasks" (Angelov et al., 2020): the former ensures that all students can complete the basic knowledge, and the latter provides opportunities for students to explore further (such as links to relevant research literature or case studies through micro-learning resources). Tasks also need to be designed to incorporate social constructivist learning concepts, such as online discussion boards or collaborative platforms that encourage peer interaction and knowledge sharing during the pre-class period. This kind of social learning can not only make up for the limitations of individual learning, but also stimulate deeper thinking through the collision of multiple perspectives. In terms of technical support, the design of pre-class learning activities should make full use of the functions of learning management system (LMS) or mobile learning platform, such as automatic scoring and instant feedback mechanism to help students adjust learning strategies in time; Through learning analysis technology, it provides teachers with visual reports of students' learning behaviours, so as to provide data support for the design of classroom activities. It is worth noting that the design of pre-class learning activities should also pay attention to the maintenance of

students' motivation and the cultivation of self-regulation ability. For example, make learning tasks more fun and challenging through gamification elements such as points, badges, or leaderboards; By setting periodic goals and reflection tasks, students can gradually form the habit of independent learning. Finally, the design of pre-class learning activities should also consider the seamless connection with classroom activities. For example, teachers can dynamically adjust the focus and form of classroom activities based on students' pre-class learning data (such as test scores, discussion participation, etc.), so as to realize the organic linkage between pre-class and class.

Optimization and adjustment of classroom activities

The optimization and adjustment of classroom activities is the core of the successful implementation of flipped classroom, whose goal is to transform the basic knowledge acquired in pre-class learning into deep understanding and application ability (Zee & Koomen, 2016). According to the constructivism learning theory, the internalization of knowledge requires a cognitive reconstruction process from passive reception to active construction, while micro-learning lays an important foundation for the in-depth development of classroom activities through precise and fragmented knowledge supply. This process requires teachers to break out of the traditional teaching mode and design multi-dimensional learning experience as a facilitator, so that the classroom can become a practical field of knowledge integration and ability development.

The optimization of classroom activities should be based on accurate learning situation analysis. With the intelligent support of micro-learning platform, teachers can systematically track students' knowledge mastery trajectory. For example, by observing clips of students repeatedly watching microvideos, high-frequency question points in online discussions, and common mistakes in assignments, teachers can create a "cognitive map" of the class. A middle school math teacher found that students were commonly confused in learning the principle of function image transformation, so he introduced dynamic geometry demonstration tools in class, combined with visual comparison of wrong solutions, and guided students to gradually clarify myths through observation, questioning and correction. This kind of teaching design based on data insight makes it possible to present abstract mathematical principles concretely, and effectively shortens students' transformation path from understanding to application.

In the form of activity organization, the combination of hierarchical design and dynamic grouping is very important. Teachers should construct a stepped task system according to students' cognitive basis and learning style. For example, in an English class of a primary school, students are divided into different groups according to their pre-class learning performance: those who have a weak grasp of vocabulary consolidate their foundation through interactive games of word pairing; intermediate students make creative adaptations around situational dialogues; and outstanding students make comparative analysis of texts from a cross-cultural perspective. This stratification is not fixed, but dynamically adjusted along with the learning process. The "mobile group" model adopted in a physics class allows students to choose between different task areas (such as experimental verification, theoretical derivation, innovative design) independently according to the learning effect of the stage, which not only respects individual differences, but also stimulates learning initiative.

The design of collaborative learning should reflect the social characteristics of knowledge construction. The application of the modified jigsaw method is a typical case: the teacher breaks down the complex knowledge system into several interrelated modules, and each "expert group" delved into a specific module, and formed a new "comprehensive group" through cross-group reorganization to solve complex problems in real situations together. This design not only promotes deep knowledge sharing, but also cultivates students' teamwork and problem-solving skills. Technical support plays a catalytic role in this process: the collaborative tagging capabilities of interactive whiteboards visualise the thought process, virtual reality technology transforms abstract concepts into perceptible dioramas, and augmented reality tools provide real-time guidance for hands-on operations. For example, in the chemistry class, students can explore the formation process of chemical bonds from multiple angles through the virtual molecular structure observation pod, transforming the abstract theory of the microscopic world into an intuitive experience.

The cultivation of metacognitive ability should run through the whole classroom activity. Teachers need to design structured reflection sessions to help students establish a sense of monitoring the learning process. A "three-dimensional reflection journal" developed by a junior high school contains three dimensions of cognition, strategy and emotion: students not only record the breakthrough of knowledge difficulties, but also analyze the learning method and its effectiveness, and reflect on the emotional experience in the learning process. With the mind map template and problem solving flow chart provided by teachers, this reflective practice enables students to gradually form self-regulating learning ability. Research shows that continuous reflective training can significantly improve students' ability to transfer knowledge in new situations.

The dynamic adjustment mechanism of classroom activities needs to establish a real-time feedback system. Intelligent classroom monitoring tools can instantly capture students' learning status, and when group cognitive impairment is found, the system automatically pushes remedial micro-resources. For example, in a biogenetics class, the teacher finds that students are generally confused about implicit decision rules through real-time monitoring of the dashboard, and then starts a backup "gene matching simulation game" instead of the original case analysis task. This flexible teaching design requires teachers to preset multiple alternative activity modules and switch flexibly according to real-time learning conditions, which not only ensures the realization of teaching objectives, but also improves the utilization efficiency of classroom time.

To realize the above optimization system, teachers need to improve data literacy and teaching wisdom simultaneously. Systematic professional training should focus on the application of learning analysis tools, the formulation of differentiated teaching strategies and the

cultivation of classroom adaptability. When teachers can proficiently interpret the cognitive laws behind the learning data and creatively design multidimensional interactive scenes, flipped classroom can truly break through the surface goal of knowledge transfer and become a practical platform for cultivating higher-order thinking and core literacy. This change not only reconstructs the relationship between teaching and learning, but also reshapes the educational value of classroom as a space for knowledge creation.

IV. Evaluation of the effect of micro-learning in flipped classroom

Quantitative analysis of learning effectiveness

Quantitative analysis of learning effectiveness is the core means to evaluate the application effect of micro-learning in flipped classroom. Multi-dimensional data collection and analysis methods are needed to systematically investigate the influence of micro-learning on students' knowledge mastery, ability improvement and learning behaviour.In terms of academic performance, the test results of the experimental group (flipped classroom supported by micro-learning) and the control group (traditional teaching mode) can be compared to reveal the promotion effect of micro-learning on knowledge internalization. For example, students in the experimental group generally outperformed students in traditional classroom in terms of concept understanding and word problem scores, indicating that micro-learning resources reduce learners' cognitive load through fragmented knowledge reorganization and focus reinforcement. At the same time, it is necessary to combine formative evaluation data to deepen analysis, such as pre-class test completion and resource access frequency recorded by micro-learning platform, to track the dynamic process of students' knowledge construction. Studies have shown that students who frequently use micro-learning resources tend to show stronger participation enthusiasm and problem-solving ability in class discussions, which confirms the potential value of micro-learning in promoting independent learning and the development of higher-order thinking.Data mining of learning behaviour provides a new perspective for effect evaluation. With the help of learning analysis technology, teachers can analyze behavioural data such as resource click heat map and learning path map to accurately identify the use efficiency of micro-learning resources. For example, the concentrated exit period of a micro-video may reflect a content design flaw, while the repeated completion of an interactive quiz suggests a positive effect on knowledge consolidation. Such analysis can not only optimize resource design, but also provide the basis for differentiated teaching – for students who frequently switch learning paths, structured learning guides can be pushed; For the knowledge of staying too long, it is necessary to supplement the auxiliary explanation materials.It should be emphasized that quantitative analysis should complement qualitative research. Relying solely on data may ignore learners' subjective experience and situational factors, so it is necessary to combine classroom observation, student interview and other methods to verify the reliability of assessment results in multiple dimensions. For example, a teacher found that although some students had a high degree of completion of micro-learning tasks, they still showed confusion about core concepts in the interview, and further analysis found that there was a shallow learning behaviour of "mechanical clicking resources". This "behaviour-cognition" dislocation phenomenon suggests that quantitative data should be comprehensively interpreted in combination with learners' cognitive state and emotional feedback.In general, the quantitative evaluation of learning effectiveness needs to construct a three-dimensional framework of "academic performance – process behaviour – cognitive development", which not only focuses on the mastery of explicit knowledge, but also explores the role of micro-learning in shaping thinking patterns and learning strategies. Through the cyclic interaction of data-driven and teaching reflection, the application efficiency of micro-learning in flipped classroom is continuously optimized.

Student satisfaction and participation survey

Student satisfaction and participation survey is an important dimension to evaluate the application effect of micro-learning in flipped classroom, which not only reflects students' acceptance of teaching mode, but also reveals the actual effect of micro-learning resources in stimulating learning motivation and promoting active participation. In terms of satisfaction, the data collected through questionnaires and focus group interviews show that students generally speak highly of the flexibility, interactivity and ease of use of micro-learning resources. For example, most students believe that the short, concise and multi-modal presentation of micro-videos (such as animations, diagrams and voice explanations) significantly reduces learning pressure and enables them to efficiently complete pre-class learning tasks in fragmented time.

Some students also pointed out that the content design of some micro-learning resources is too simple and fails to fully explain complex concepts, which suggests that teachers need to further balance brevity and depth in resource development. In terms of engagement, through the analysis of behavioural data of micro-learning platform (such as resource access frequency, interaction frequency and task completion rate), it can be found that students' participation level is significantly positively correlated with their learning effectiveness. For example, students who frequently participate in online discussions and complete extension tasks tend to show stronger critical thinking and problem-solving skills in classroom activities. The introduction of gamification elements such as points, badges and leaderboards has also been shown to be effective in increasing student motivation, especially in competitive learning environments where students are more likely to actively explore micro-learning resources for additional rewards. It is worth noting that the improvement of participation is not only reflected in the behavioural level, but also reflected in the emotional and cognitive investment of students. For example, by mining the discussion text through sentiment analysis technology, it can be found that students show higher learning interest

and confidence when using micro-learning resources. At the same time, the investigation also revealed some potential problems, such as some students do not adapt to the fragmented mode of micro-learning, which may lead to the isolation and systematic loss of knowledge. Therefore, when designing and implementing micro-learning resources, teachers should pay attention to guiding students to integrate fragmented knowledge into a systematic cognitive structure, so as to maximize their learning effect.

Teacher feedback and teaching reflection

Student-Teacher feedback and teaching reflection are the key perspectives to evaluate the application effect of micro-learning in flipped classroom, which not only reveals the profound impact of teaching mode transformation on the role of teachers, but also provides practical wisdom for the continuous optimization of teaching design. Teachers generally believe that the introduction of micro-learning resources has significantly improved the implementation efficiency of flipped classroom, especially in the pre-class knowledge transfer process. The use of micro-videos and interactive tests has reduced the burden of repeated explanation and enabled teachers to devote more energy to personalized instruction and the cultivation of higher-order thinking in class. Some teachers also pointed out that the design and development of micro-learning resources requires a lot of time and technical ability, which puts higher requirements on teachers' digital literacy. For example, one teacher said in his reflection, "Making high-quality micro-videos requires not only mastering the recording and editing tools, but also balancing simplicity and depth in content design, which is a big challenge for us." Teacher feedback also reveals the potential value and limitations of micro-learning in the design of classroom activities. For example, by analyzing students' pre-class learning data, teachers can more accurately identify students' knowledge blind spots and design more targeted classroom activities (such as group discussions or problem-solving tasks); But at the same time, teachers also found that over-reliance on micro-learning resources may lead to the homogenization of classroom activities, weakening the creativity and flexibility of teaching. The teaching reflection also emphasizes the transformation of teachers' role in flipped classroom - the transformation from "knowledge imparts" to "learning guides" requires not only the improvement of teaching skills, but also a profound transformation of educational ideas. For example, one teacher reflected: "In a traditional classroom, I am used to controlling the entire teaching process, while in a flipped classroom, I need to learn to let go and let the students become the subject of learning, which is a new experience for me." Notably, teacher feedback also called for schools to provide more technical support and professional development opportunities, such as through workshops or collaborative platforms, to help teachers share their experiences in micro-learning resource design and flipped classroom implementation.

V. DISCUSSION

This study systematically discusses the application and effect of micro-learning in flipped classroom, and reveals its significant role in improving students' learning effectiveness, satisfaction and engagement. Research shows that the fragmented and modular features of micro-learning are highly compatible with the autonomous learning needs of flipped classroom, which can effectively reduce cognitive load and promote the deep internalization of knowledge. In terms of application design, the development and integration of micro-learning resources, the design of pre-class learning activities and the optimization of classroom activities are the key links of successful implementation. The effect evaluation shows that micro-learning not only significantly improves students' academic performance, but also enhances students' learning motivation and engagement through multi-modal interaction and gamification elements. However, the study also points out that micro-learning still faces challenges in resource development, student adaptability and teacher role transformation. Future studies should further explore the applicability of micro-learning in different disciplines and education stages, and strengthen technical support and teacher professional development to promote the continuous optimization and innovation of flipped classroom. This study provides practical guidance for educators and theoretical basis for the deep integration and innovation of educational technology.

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