Practice on the Teaching Design of the Cellular Respiration and Photosynthesis Unit under the 5E Instructional Model

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Abstract: Cellular Respiration and Photosynthesis are important teaching content of Energy Metabolism in Biology, with abstract concepts and complex microscopic processes. Teaching process suffers from problems such as misconception, weak experiment inquiry, and monolithic evaluation methods. The 5E instructional model is based on constructivism and revolves around the five phases of engagement, exploration, explanation, elaboration and evaluation to conduct concept construction. This paper analyzes the practical contradictions in the traditional teaching of this unit, elaborates on the logical basis for the 5E model to adapt to unit teaching, studies the design approaches and practical challenges of unit teaching, and summarizes the directions and practical pathways of teaching innovation and reform, aiming to provide ideas for the overall teaching reform of Biology in higher education.

Keywords: 5E Instructional Model; Cellular Respiration and Photosynthesis; Unit Teaching Design; Scientific Inquiry

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1.Introduction

Under the guidance of biological core competencies, overall unit teaching design has become an important direction for the reform of college Biology courses. As the key components of Cellular Energy Metabolism, Cellular Respiration and Photosynthesis serve as the key carriers for students to develop the philosophy of matter and energy. However, due to inability to directly feel and experience the micro reaction process, students are prone to inveterate misconceptions. Moreover, traditional lecture-based teaching is challenging to achieve the goal of deep concept construction. The 5E instructional model is based on the logic of inquiry-based learning and breaks through the limitations of fragmented class-hour teaching. It can integrate and restructure unit content, and enables students to proactively explore and construct knowledge rather than passively memorize knowledge. This paper integrates the requirements of the new teacher education curriculum in higher education to tease out the practice logic, practical dilemmas, and optimization pathways of the 5E model in the teaching design of this unit. This can provide reference for other core concept teaching reform in Biology.

2.The Practical Dilemmas and Model Adaption Logic in the Teaching of the Cellular Respiration and Photosynthesis Unit

2.1 *Practical Dilemmas in the Traditional Unit Teaching*

Cellular Respiration and Photosynthesis embody the big concepts of Matter Cycle and Energy Conversion. They are crucial components of the general Biology curriculum. Under the constraints of the traditional teaching paradigm, numerous contradictions have long hindered the improvement of teaching quality. Regarding knowledge transmission, classrooms mainly focus on imparting conclusive knowledge, emphasize the memorization of fragmented knowledge such as reaction stages, reaction sites, and chemical equations, and lack the process of concept generation, which cuts off the tie of unity of opposites between the two physiological processes. Students rely on mechanical memorization to pass academic exams. They fail to establish a systematic cognitive framework for energy metabolism. Regarding experimental teaching, due to various factors such as class-time constraints, experimental conditions, and teaching inertia, exploratory modules have been continuously reduced. A large number of exploratory activities have transformed into confirmatory demonstration operations. Some even substitute

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practical operations with theoretical explanations. Students lack comprehensive training opportunities for proposing hypotheses, designing experimental schemes, processing experimental data, and deriving scientific conclusions. Experiments have become appendages of theoretical knowledge, and it is difficult to achieve the goal of cultivating scientific inquiry capabilities. Regarding teaching evaluation, it emphasizes outcomes over processes, focuses mainly on summative paper-and-written tests, assesses the memorization of fragmented knowledge points, and lacks dynamic observation of students' advanced ability such as scientific thinking and inquiry practice. It cannot fully reflect the authentic development status of students' core scientific literacy.

2.2 *The Internal Adaption Logic of the 5E Instructional Model and Unit Teaching*

The 5E instructional model is based on the constructivist learning theory to progressively conduct teaching activities in accordance with the five phases of engagement, exploration, explanation, elaboration, and evaluation. Its underlying principle is highly compatible with the teaching improvement requirements of the Cellular Respiration and Photosynthesis unit. This model is centered on students' concept construction and places inquiry at the core of teaching activities. It is different from the teacher-led knowledge transmission model. It can guide students to show their existing knowledge through situational conflicts, obtain evidence through inquiry activities, and autonomously update their concepts. It is specifically designed to address students' existing misconceptions. From the perspective of overall unit planning, the 5E model does not remain confined to the design of single-lesson activities. It can serve as the guideline for the top-level design of a unit. It transcends the linear arrangement of the teaching materials and integrates Cellular Respiration and Photosynthesis into the broad theme of Cellular Energy Metabolism, which achieves the integration of macroscopic unit planning and microscopic class activities [1]. The five teaching phases feature flexible nesting. They can cooperate with the blended teaching design to put partial complex cognitive tasks before class, and resolve the contradictions between the complex unit teaching content and limited class time.

3.Implementation Pathways for the Overall Unit Teaching Design under the 5E Model

3.1 *Restructuring of Unit Teaching Content, and Establishment of the Five-Phase Task Chain*

The unit teaching design should abandon the idea of designing each knowledge point separately, use the big concept of Cellular Energy Metabolism to command the teaching content of the whole unit and constructing a complete 5E task chain with misconception transformation as the ultimate goal. The "engagement" phase should start from real-life scenarios to raise driving questions, and leverage real phenomena such as muscle soreness after exercise and the matter sources of plant dry weight to trigger cognitive conflicts, activate students' existing preconceptions, fully expose cognitive misunderstandings, and define the research directions of this unit. The "exploration" phase should renovate and upgrade the original verification experiments, and create gradient inquiry tasks that include both large-scale exploratory experiments and micro-scale inquiry activities. Through a series of activities such as exploration of the yeast cell respiration methods and the impact of environmental factors on photosynthesis intensity, students can fully experience the scientific inquiry process of variable control, phenomenon observation, and data collection so as to provide empirical materials for concept formation. The "explanation" phase should be based on students' inquiry outcomes to guide students to autonomously expound life phenomena using experimental data. On this basis, teachers introduce normative academic concepts to realize the shift from the understanding of phenomena toward scientific theories. Digital and visual methods are used to address issues that the microscopic physiological processes cannot be directly observed to help students form specific imagination of microscopic processes such as ATP synthesis and electron transfer. The "elaboration" phase should set authentic scenarios such as agricultural greenhouse cultivation and loosening and tilling the soil in fields to prompt students to apply the unit knowledge to analyze practical problems, achieve the expansion and deepening of concepts and break down the barriers between theoretical knowledge and practical application [2]. The "evaluation" phase should run through process observation and final tests, and incorporate the depiction of concept maps, the planning of experimental schemes, the performance of group collaboration, and the outcomes of the "elaboration" tasks into the evaluation scope to enable a comprehensive consideration of conceptual understanding, inquiry ability, and thinking quality.

3.2 *Gradient Design of the Experimental System*

The exploratory experiments are important carriers for implementing the 5E instructional model. To address the issues of high cost, long period and difficulty in classroom organization in unit experiments, they should establish a new experimental system that improves mainstream experiments, and complement them with micro-Inquiry activities so as to enhance the popularity of inquiry-based teaching. The traditional verification experiments should be carried out unconfined improvement to change the experimental task objects, transform the verification of foregone conclusions into variable investigation tasks, and enhance the openness of tasks while maintaining the core experimental logic to leave students with the space for planning and adjusting the experimental schemes by themselves. And, they should develop micro inquiry activities with short cycles, easily accessible materials, and simple operations as supplements. These micro inquiry activities do not rely on complex instruments and equipment, take less time, and ensure that all students can participate in the inquiry practice and complete scientific thinking training within the limited class time. They make up for the deficiencies of insufficient frequency in conducting large-scale exploratory experiments. In addition, they should build a tiered inquiry scaffold to form a task ladder from structured inquiry to guided inquiry, and assign inquiry tasks with tiered openness to students with varying cognitive foundations so as to achieve differentiated teaching and meet the development needs of students at different levels. Concurrently, they should supplement with corresponding experimental guidance plans to define the classroom organization methods, avoid chaotic and disorderly situations that may occur in the open inquiry classrooms, ensure the smooth progress of the inquiry activities, and enable students to become true researchers rather than mechanical operators.

3.3 *Establishment of an Embedded Multi-Dimensional Evaluation System*

Higher education institutions should establish an embedded and process-oriented evaluation system based on the teaching objectives of each 5E teaching phase, and transform advanced qualities such as scientific inquiry and critical thinking into observable and assessable behavioral indicators to resolve the practical difficulty that advanced capabilities struggle to be assessed. In the “engagement” phase, it is necessary to identify students’ preconceptions through pre-class mind maps and classroom Q&A. In the “exploration” stage, it is necessary to record the processes of experimental operations, group cooperation, and experimental scheme design, etc. During the “explanation” phase, it is necessary to analyze the construction of concepts through concept maps and students’ expressions. In the “elaboration” phase, it is necessary to carry out performance-based evaluation after completing assignments in authentic task contexts. Finally, the comprehensive evaluation is conducted through the final test of the unit. Higher education institutions should develop standardized evaluation scales to minutely subdivide dimensions such as experimental design and implementation, the application of scientific evidence, and group cooperation, and transform empirical judgment into evidence-based evaluation models so as to make evaluation tools more concrete. Evaluation should integrate throughout the whole teaching process to provide feedback on students’ learning situations at any time and offer teachers the basis for promptly adjusting teaching progress and improving teaching activities in order to achieve the fundamental objectives of evaluation-driven teaching and evaluation-driven learning and no longer rely solely on paper-and-written tests to measure learning outcomes.

4.Challenges in Teaching Practice and Their Solutions

4.1 *Contradictions Between the Implementation of the Teaching Model and the Allocation of Class Hours and Resources*

The complete 5E inquiry cycle requires sufficient time support. However, the total class hours are limited in higher education, and there are numerous knowledge points in each unit. This leads to contradictions of time between inquiry activities and theory teaching and causes the realistic difficulty that teaching tasks cannot be fulfilled on time. The blended teaching design can be adopted to optimize the time allocation, putting the learning tasks of the "engagement" phase, such as context preview and preliminary understanding of concepts, before class to enable students to use micro-lessons or learning task sheets to learn by themselves and leave more class time for teaching activities with high educational value such as collaborative inquiry, exchange of views, and concept explanations. The teaching content of the unit should be integrated integrally to clarify the logical relationships among the knowledge points, eliminate repetitive teaching steps, establish a knowledge framework of Cellular Respiration and Photosynthesis, and avoid the redundancy of content caused by fragmented class hours [3]. Classroom inquiry activity processes should be improved to forecast the time boundaries of the inquiry activities and carry out task stratification well by leveraging the preliminary teaching design. The fundamental tasks should be designed to ensure that all students can fulfill them. The extended inquiry tasks, on the other hand, should be carried out by students autonomously during their after-school time, which adapts to the allocation of study hours while maintaining the core position of inquiry activities.

4.2 *Cognitive Transformation Dilemmas of Abstract Micro Concepts*

Important processes, such as Cellular Respiration and Photosynthesis, occur within organelles. Matter changes and energy conversion are micro reaction that is invisible to the naked eye, which makes it difficult for students to form a clear intuitive impression. Even if exploratory experiments are carried out, students can only observe external macroscopic phenomena, which makes them struggle to establish a connection between macroscopic phenomena and microscopic molecular reaction and prone to misconceptions again. Digital teaching resources should be fully leveraged. Teachers can leverage 3D animation and interactive simulation models to present the motion of microscopic matter and energy transfer process visually and help students form corresponding representation during the explanation process to address the cognitive misalignment between macroscopic phenomena and microscopic mechanisms. The teaching design should be targeted at and centered around typical misconceptions, leverages contextual questions to fully expose students' incorrect understanding and sets targeted inquiry tasks to collect counter-evidence so as to shock students' incorrect cognition with evidence in the "engagement" phase, corrects misconceptions in the "explanation" phase, and sets same types of analysis tasks to consolidate correct cognition in the "elaboration" stage, thereby building a complete concept transformation pathway of "exposure → correction", and reducing the repeated occurrence of misconceptions.

5.Value and Practice Expansion of the Unit Teaching Reform under the 5E Instructional Model

5.1 *The Multi-Dimensional Educational Value of Teaching Reform*

Carrying out teaching reform of the Cellular Respiration and Photosynthesis unit under the 5E model can promote the synergetic development of students, teachers and course construction. From the perspective of students, the unit teaching reform targets at deep knowledge construction. It helps students clarify the connections between the two physiological processes in matter and energy, and eliminate inveterate misconceptions. The complete inquiry operation chain has cultivated students' experimental planning, data analysis and scientific verification capabilities, established view of life in the process of solving problems of situational tasks, built the connections between biological knowledge and the real world, and optimized scientific literacy. Students majoring in teacher education can personally experience the whole process of inquiry-based teaching during their course learning. This can enhance their own teaching capabilities and provide reference samples for their future practice in basic education positions. From the perspective of teachers, the complete unit development and the iterative process of multiple rounds of action research prompt teachers to change their original teaching philosophy, enhance their overall unit design, inquiry activity development, and process-based evaluation design and other research capabilities, and drive teachers to shift from mere knowledge imparters to organizers and guides of learning activities. Regarding courses, the implementation of the unit reform has enriched the teaching cases of general biology courses, provided empirical evidence for the teaching improvement of core biological concepts, and expanded the resource reserve for inquiry-based teaching of the courses.

5.2 *Radiation of the Achievements and Their Cross-Scenario Transfer and Application*

The reform achievements of this unit have multi-faceted radial transfer significance. On campus, its experience can be applied to other courses of Life Science. Regarding overall unit restructuring, gradient inquiry development, embedded evaluation creation and other aspects, its idea can be referenced to promote the innovation process of other experimental courses. Moreover, through teaching research activities and public lectures, the experience can be exchanged among different teacher education disciplines on campus [4]. Among schools, we can rely on teaching research exchanges to share complete examples of unit reform so as to provide a referable practice model for local comparable institutions to implement the reform of Biology courses. Relevant institutions can make localized adjustment to the provided resource packages based on their own realities and hardware conditions and then carry out teaching practice that aligns with their own realities. From an interdisciplinary perspective, the overall unit design conceptualization scheme, gradient inquiry development methods and teaching reform idea of the project can all serve as valuable reference materials.

6.Conclusion

The 5E instructional model provides a mature operational framework for addressing the problems in the traditional teaching of the Cellular Respiration and Photosynthesis unit. Its important significance does not lie in simply applying fixed teaching phases, but rather implementing inquiry-based teaching, conceptual change, and multiple evaluation through the overall restructuring of the unit. The unit teaching design under the 5E model takes students' concept construction as its fundamental goal. It considers the educational needs of knowledge acquisition, capability cultivation, and quality improvement simultaneously. It cannot only optimize the teaching quality of core biological concepts, but also provide a reproducible practical pathway for the reform of biology courses under the background of new teacher education in higher education. Subsequently, we should carry out continuous teaching reform, and further improve the teaching design system to fully achieve the educational function of inquiry-based teaching.

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