

# UbD-empowered BOPPPS teaching model for senior high school biology: a case study of "proteins are the primary executors of life activities"

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**Abstract.** Against the backdrop of the new curriculum standards, senior high school biology education places greater emphasis on cultivating students' core competencies and advocates a learning approach that prioritizes understanding. "Proteins Are the Primary Executors of Life Activities" is a key topic in Biology Compulsory 1. Guided by the Understanding by Design (UbD) framework, this study reconstructs the Bridge-In, Objectives, Pre-assessment, Participatory Learning, Post-assessment, Summary (BOPPPS) instructional model and develops a three-stage teaching pathway consisting of pre-class self-diagnosis, in-class meaning construction, and post-class transfer and application. Using "Proteins Are the Primary Executors of Life Activities" as the instructional context, the study designs and implements a complete teaching process, covering goal formulation, assessment evidence development, and the six instructional stages of the BOPPPS model, followed by classroom practice. The results demonstrate that the integrated teaching model effectively promotes students' deep understanding of biological concepts and facilitates the development of core competencies, including life concepts and scientific thinking. The study therefore provides a practical reference for teaching abstract concepts in senior high school biology.

**Keywords:** Understanding by Design (UbD), BOPPPS model, senior high school biology, teaching practice

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## 1. Introduction

The *General Senior High School Biology Curriculum Standards (2017 Edition, Revised in 2020)* explicitly state that biology teaching at the senior high school level should aim to cultivate students' core competencies by encouraging active engagement in the learning process and enabling them to develop scientific thinking and establish sound life concepts through inquiry, understanding, and application [1]. Concepts constitute the foundation of the biological knowledge system, and the quality of abstract concept instruction directly determines the development of students' disciplinary competencies. "Proteins Are the Primary Executors of Life Activities" is a key chapter in *Molecules and Cells*, the first compulsory biology textbook published by the People's Education Press. It encompasses a series of interconnected topics, including the structure of amino acids, dehydration synthesis of amino acids, the spatial structure of proteins, and protein functions. Owing to its high level of conceptual abstraction and extended chains of logical reasoning, this topic represents both one

of the major challenges encountered by beginning biology learners and an important vehicle for fostering students' understanding of the relationship between structure and function as well as their logical reasoning abilities.

In conventional classroom practice, two prominent problems are commonly observed. First, instruction tends to follow a knowledge-transmission approach. Teachers usually explain concepts sequentially according to the textbook, placing primary emphasis on concept memorization and exercise-based practice while overlooking students' prior knowledge. Consequently, students often fail to establish meaningful connections among concepts, and their learning remains at the level of rote memorization rather than deep understanding. Second, although many teachers adopt the traditional BOPPPS instructional model, they typically apply only its in-class components, such as the bridge-in, participatory learning, and post-assessment stages, thereby separating pre-class instructional design from classroom implementation. In addition, assessment is frequently treated merely as a concluding activity for checking knowledge acquisition, rather than serving its essential diagnostic, instructional, and motivational functions, which is inconsistent with the fundamental principles of deep learning.

The Understanding by Design (UbD) framework advocates a backward design process in which teachers first identify the desired learning outcomes, then determine acceptable assessment evidence, and finally plan instructional activities accordingly [2]. By positioning assessment at the forefront of instructional design and emphasizing students' conceptual understanding and knowledge transfer as the ultimate goals of teaching, the UbD framework effectively addresses the limitations of both traditional classroom instruction and the conventional BOPPPS model. This study therefore integrates the UbD framework with the BOPPPS instructional model to reconstruct the overall teaching framework. Taking "Proteins Are the Primary Executors of Life Activities" as an example, it develops a complete instructional design and conducts classroom implementation to explore an effective approach for teaching abstract concepts in senior high school biology. The study seeks to bridge the gaps among instructional design, classroom implementation, and continuous assessment by establishing a comprehensive three-stage learning pathway that supports students in constructing conceptual understanding and transferring knowledge flexibly. It also provides a practical instructional model that can serve as a reference for biology teachers teaching similar topics.

## **2. Related concepts and theoretical foundations**

### **2.1. The Understanding by Design (UbD) framework**

The Understanding by Design (UbD) framework is one of the most influential instructional design theories in contemporary education. Unlike the traditional forward-design approach, which begins with textbook content and instructional delivery, UbD emphasizes understanding first and backward design. It takes the intended learning outcomes as the starting point of instructional planning and consists of three core stages [3]. The first stage is identifying the desired learning outcomes, in which teachers determine the knowledge, competencies, and core literacy students are expected to acquire by integrating curriculum standards with learners' characteristics and prior knowledge. The second stage is determining acceptable assessment evidence, where diversified assessment tasks and evaluation tools are designed to establish whether students have genuinely achieved conceptual understanding. The third stage is planning learning experiences and instruction, in which classroom procedures, inquiry tasks, and learning activities are systematically developed in alignment with the intended outcomes and assessment evidence [4].

## 2.2. The BOPPPS instructional model

The BOPPPS instructional model is a well-established classroom teaching framework that originated in Canada. Owing to its clear structure and strong emphasis on student interaction, it has been widely adopted across various disciplines. The model divides a complete lesson into six instructional stages. Bridge-in (B) introduces the lesson and stimulates students' interest in learning. Objective (O) clarifies the learning goals and expected outcomes of the lesson. Pre-assessment (P) diagnoses students' prior knowledge and learning readiness. Participatory Learning (P) engages students in interactive learning activities such as inquiry, discussion, and collaborative exploration. Post-assessment (P) evaluates students' learning outcomes and the effectiveness of instruction. Finally, Summary (S) consolidates key concepts and organizes the knowledge structure acquired during the lesson. The BOPPPS model standardizes classroom procedures and effectively enhances student engagement. However, the original model also exhibits notable limitations. Its application is generally confined to the approximately 40-minute classroom session and lacks a comprehensive pre-class instructional design component. Moreover, assessment is positioned at the end of the lesson and is primarily used as a summative measure of learning outcomes. As a result, it provides limited opportunities for timely feedback on students' learning difficulties and cannot fully realize the principle of using assessment to promote learning [5].

## 3. Reconstruction of the BOPPPS model under the understanding by design framework

**Core competency-oriented principle.** The reformed instructional model is guided by the four core competencies of senior high school biology. All objectives, instructional activities, and assessment designs are organized around life concepts, scientific thinking, scientific inquiry, and social responsibility. The study integrates competency cultivation throughout the entire teaching process, thereby moving beyond a purely knowledge-centered orientation.

**Assessment-first principle [6].** In strict accordance with the requirements of the UbD backward design framework, diagnostic assessment, formative assessment, and summative assessment are introduced at the planning stage and embedded throughout the teaching process. Assessment is thus positioned as a foundational basis for instructional design and classroom activities, enabling a shift toward "teaching guided by assessment" and "learning promoted through assessment."

**Cognitive progression principle.** Following the cognitive trajectory of activating prior knowledge → constructing meaning → transferring learning, the model establishes a three-stage learning pathway. This ensures a progressive sequencing of pre-class, in-class, and post-class learning activities and aligns with the cognitive characteristics of senior high school students.

Sheng Qunli has proposed three types of instructional objectives: knowledge acquisition, meaning construction, and knowledge transfer [7]. Building on this framework, and integrating UbD backward design logic, the original BOPPPS instructional structure, and the cognitive development characteristics of senior high school students, the present study reconstructs the six BOPPPS instructional components within a UbD-aligned three-stage design. This ultimately forms a progressive learning process consisting of pre-class self-diagnosis, in-class meaning construction, and post-class transfer and application.

## 4. Instructional design for "proteins are the primary executors of life activities" based on the integrated model

Using the reconstructed instructional framework, this study takes the lesson "Proteins Are the Primary Executors of Life Activities" from *Biology Compulsory 1* (People's Education Press edition) as an illustrative example. The instructional design comprises three components: UbD-based backward design before class, implementation of the six BOPPPS instructional stages during class, and post-class transfer and application. The lesson is designed for first-year senior high school students and is scheduled for a single 40-minute class period.

### 4.1. Pre-class: UbD-based backward design

First, the desired learning outcomes are determined. Based on curriculum standards, textbook content, and student learning conditions, a tiered set of three-dimensional learning objectives is established, integrating knowledge, skills, and core competencies. The learner analysis and instructional objectives are as follows.

**Learner analysis.** First-year senior high school students have already mastered the basic composition of cells and are familiar with terms such as proteins and amino acids. However, they lack understanding of microscopic structures and biochemical reaction processes. They are prone to confusion regarding the relationships among amino acids, polypeptides, and proteins, and often exhibit significant conceptual misconceptions.

Learning objectives are as follows.

**Knowledge objectives:** Students should be able to state the general structural formula and structural characteristics of amino acids; explain the process of amino acid dehydration synthesis; clarify the reasons for the structural diversity of proteins; and provide examples of the five major physiological functions of proteins.

**Ability objectives:** Students should be able to identify amino acids based on their structural formula; analyze the relationship between protein structure and function through model construction and logical reasoning, thereby enhancing scientific thinking skills.

**Core literacy objectives:** Students should develop the life concept that "structure is adapted to function"; cultivate cooperative inquiry abilities through group-based exploration; and recognize the practical relevance of biological knowledge through examples of protein applications in daily life.

Next, assessment evidence is designed. Based on the expected learning outcomes, three categories of assessment tools are developed to correspond to different stages of learning. Diagnostic assessment (pre-class self-diagnostic test). The teacher designs five multiple-choice questions and two short-answer questions to assess students' prior understanding of proteins in everyday life, prerequisite chemistry knowledge, and foundational knowledge of cellular compounds. This assessment is used to identify students' baseline understanding and help them conduct self-diagnosis before class. For formative assessment, classroom observation rubrics and scoring criteria are developed around key learning tasks such as amino acid identification, dehydration synthesis modeling, and protein function analysis. These tools enable real-time evaluation of students' participation and conceptual understanding during classroom activities. In addition, the teacher designs both foundational consolidation exercises and contextual application tasks. The basic exercises assess mastery of core concepts, while the contextual tasks evaluate students' ability to transfer knowledge to real-life situations.

**Pre-class self-diagnosis.** The teacher distributes the diagnostic test prior to instruction to identify students' weak areas and common misconceptions, thereby adjusting teaching pace and instructional strategies to support in-class implementation.

Finally, the overall instructional design is established. The study embeds learning objectives throughout the teaching process and decomposes them into concrete guiding questions in advance, which are then presented to students during class. Accordingly, the design shifts objective formulation to the pre-class stage and situates problem-solving within classroom learning. Based on the alignment of objectives and assessment, the overall instructional flow is organized as follows: pre-class diagnostic test → classroom bridge-in with guiding questions → group inquiry and participatory learning → continuous formative assessment → teacher–student synthesis and conceptual organization → differentiated post-class assignments.

Meanwhile, the teacher prepares instructional resources including ball-and-stick molecular models of amino acids, as well as eggs, milk, beef, and multimedia animations.

## 4.2. In-class: implementation of the reconstructed BOPPPS instructional model

### 4.2.1. Stage 1: bridge-in (B) (5 minutes)

Based on students' overall performance in the pre-class diagnostic assessment, the teacher briefly summarizes the common learning difficulties identified in the class. A real-life contextual introduction is then employed, in which samples and images of eggs, milk, beef, and enzyme preparations are presented. Students are prompted with the questions: "Why do we need to consume protein in our daily life?" and "What changes do dietary proteins undergo after entering the human body?" Based on students' responses, the teacher introduces the topic of the lesson, stimulates students' interest in inquiry, and smoothly transitions to the learning of new content.

### 4.2.2. Stage 2: participatory learning (P) (23 minutes)

This stage constitutes the core of students' meaning construction and is designed as a sequence of progressive inquiry activities. Activity 1: Understanding amino acids. Students are presented with structural formulas of various organic compounds and are guided to work in groups to identify the common structural features of amino acids. They then summarize the general structural formula of amino acids and establish criteria for identifying amino acids, thereby addressing the first key knowledge point. Activity 2: Simulating dehydration synthesis. Using ball-and-stick molecular models, students manually simulate the process by which two or more amino acids form polypeptides. Combined with animations, they deepen their understanding of peptide bond formation and learn how to calculate the number of water molecules released during dehydration synthesis, thereby clarifying the microscopic transformation process. Activity 3: Analyzing protein structure and function. Based on images showing different protein structures and functions, students engage in group discussions around the question: "Why do proteins exhibit such significant functional diversity?" Through collaborative analysis, they summarize the factors contributing to protein structural diversity.

### 4.2.3. Stage 3: formative assessment (P) (7 minutes)

The teacher conducts in-class questioning focusing on key points such as amino acid identification and dehydration synthesis calculations. Students' inquiry performance is evaluated using a classroom observation rubric. Within each group, students also check each other's molecular model constructions and identify potential errors. Misconceptions identified in the pre-class diagnostic assessment are specifically addressed and corrected during this stage to consolidate newly acquired knowledge in real time.

### 4.2.4. Stage 4: summary (S) (5 minutes)

The teacher and students collaboratively construct a mind map to organize the logical sequence of "amino acids → polypeptides → proteins." They systematically summarize protein structural characteristics, the causes of structural diversity, and physiological functions, thereby integrating fragmented knowledge into a coherent conceptual framework and deepening understanding. Finally, the teacher briefly introduces the

everyday phenomenon of protein denaturation, leaving an open-ended question to create cognitive suspense and smoothly transition to post-class learning tasks.

#### 4.3. Post-class: transfer, application, and learning verification

Post-class learning tasks are differentiated to accommodate students with varying levels of proficiency. At the foundational level, students complete textbook exercises designed to consolidate the core concepts of amino acids and proteins while verifying their mastery of fundamental knowledge. At the advanced level, students undertake contextualized transfer tasks based on authentic situations, such as high-temperature sterilization, alcohol disinfection, and the greater digestibility of cooked eggs. They analyze how changes in protein structure influence protein function, thereby demonstrating their ability to transfer biological concepts to real-life contexts. In addition, students complete a brief self-reflection task in which they identify concepts that remain unclear after the lesson, promoting metacognitive reflection and further conceptual understanding. After collecting and reviewing students' assignments, the teacher analyzes their overall performance and conducts the final summative assessment to evaluate learning outcomes and inform subsequent instruction.

### 5. Teaching practice: outcomes and reflections

The proposed instructional design was implemented in a regular first-year senior high school biology class. Based on classroom observations and students' learning performance, the overall teaching outcomes were positive. From the perspective of students' learning engagement, the pre-class self-diagnostic assessment enabled students to identify deficiencies in their prior knowledge before entering the classroom, making subsequent learning more focused and purposeful. During class, participatory activities such as group inquiry and molecular model construction effectively stimulated students' interest and engagement. Most students actively participated in discussions and hands-on activities, replacing the passive learning patterns commonly observed in traditional lecture-based instruction.

In terms of conceptual understanding, the assessment-driven instructional design allowed the teacher to identify and correct common misconceptions in a timely manner, such as the beliefs that all organic compounds are amino acids or that the number of amino acids is always equal to the number of peptide bonds. Post-class assessment results showed a noticeable improvement in students' mastery of the core concepts. Furthermore, students demonstrated substantially higher accuracy on contextualized transfer tasks based on authentic situations, outperforming students in parallel classes taught through conventional instructional approaches. Regarding the development of core competencies, students gradually established the life science concept that biological structure is adapted to biological function through molecular model construction and logical reasoning activities. Their scientific thinking skills were also effectively strengthened throughout the inquiry process. Overall, the anticipated competency-based learning objectives were largely achieved.

Compared with both traditional teaching approaches and the original BOPPPS instructional model, the integrated model successfully realizes the integration of teaching, learning, and assessment. Assessment is embedded throughout the entire instructional process—from pre-class preparation to in-class learning and post-class evaluation—fully utilizing its diagnostic and instructional functions to improve the precision and effectiveness of teaching. Moreover, the three-stage learning pathway, consisting of pre-class self-diagnosis and activation of prior knowledge, in-class meaning construction, and post-class transfer and application, aligns closely with students' cognitive development and effectively addresses the challenges associated with learning abstract biological concepts. Each instructional stage is explicitly aligned with clearly defined

learning objectives and assessment evidence, transforming classroom teaching from a series of disconnected activities into a coherent process centered on deep conceptual understanding.

Several limitations were also identified during implementation. First, participatory learning activities required relatively substantial classroom time, and some students with weaker academic foundations found it difficult to keep pace with their group members, resulting in lower levels of participation. Future implementations could establish heterogeneous learning groups in advance, encourage peer support, and streamline repetitive inquiry activities to improve instructional efficiency. Second, the contextualized post-class transfer tasks were relatively limited in scope and provided insufficient opportunities to foster higher-order thinking. Future research could incorporate more experimental inquiry tasks and open-ended problem-solving activities to further enhance students' creativity and their ability to apply biological knowledge in integrated contexts. Overall, the reconstructed instructional model demonstrates strong suitability for senior high school biology teaching and has considerable potential for broader classroom application.

## 6. Conclusion

"Proteins Are the Primary Executors of Life Activities" represents a typical lesson involving abstract biological concepts at the senior high school level. Conventional instructional approaches often struggle to meet the demands of deep learning and competency-based education. This study integrates the Understanding by Design (UbD) framework with the BOPPPS instructional model to develop a three-stage integrated teaching framework and applies it to a complete instructional design and classroom implementation. Classroom practice demonstrates that, by emphasizing assessment-driven instruction and understanding before content coverage, the reconstructed model effectively promotes students' conceptual meaning construction and knowledge transfer while enhancing overall instructional quality. The proposed instructional framework is applicable not only to protein-related topics but also to the teaching of other abstract biological concepts, including carbohydrates, nucleic acids, and enzymes. It therefore offers a practical reference for the reform of concept-based instruction in senior high school biology. Future research will focus on further refining assessment instruments and inquiry activities to maximize the pedagogical value and broader applicability of the integrated instructional model.

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