Proceedings of the 2nd International Conference on Interdisciplinary Humanities and Communication Studies
DOI: 10.54254/2753-7048/49/20231809

Effect of Cognitive Context-Based Modeling Instructional Strategies in Biology Concept Teaching: An Educational Action Study

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Abstract: This study uses educational action research to investigate the practical impact of cognitive context-based modeling instructional strategies in the teaching of biological concepts in high schools. The study recruited 57 high school seniors who were instructed in biology concepts in a traditional lecture-based classroom, using convenient sampling. Throughout the study, teachers used self-designed questionnaires and student classroom engagement observation scales to evaluate how often students previewed new concepts and their classroom engagement. The questionnaire results compared how often students previewed new biological concepts before and after implementing the modeling teaching strategy, revealing a significant increase from 20 to 38 students who consciously and frequently previewed new concepts. In addition, we performed a multivariate analysis of variance on the measured data obtained from the classroom participation observation scale under the two teaching strategies, which revealed significant differences in teacher's effective coaching strategy, student's response status and response quality. The key conclusion from this action study is that the use of cognitive context-based modeling teaching strategies in high school biology significantly enhances the frequency with which students preview new concepts and their classroom engagement. This research provides an empirical basis and valuable references to improve teaching approaches.

Keywords: Cognitive Context, Modeling Instructional Strategies, Educational Action Study In High School

1. Introduction

1.1. Importance and Challenges of Teaching Concepts in High School Biology

Numerous abstractly summarized concepts in biology relate to life phenomena, interrelationships, and characteristics. Concept learning is one of the essential teaching contents in biology. As per the Biology Curriculum Standards for Compulsory Education (2011 Edition), biological concepts are at the core of the discipline. To assist students in developing accurate biological concepts, educators must furnish them with comprehensive and illustrative information, while also guiding them to form concepts through the abstraction and generalization of facts.

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Nonetheless, instructing concepts is not merely a matter of defining terms and offering examples. Students face numerous obstacles in comprehending biology concepts in the conventional lecture-based classroom. These include contradictions between the definition of a given concept and its examples, confusion regarding the substantive meaning of the concept, inability to integrate concept learning with the cultivation of dialectical thinking, and more. These issues are all related to the failure of traditional biology instruction to fully guide students in actively participating in the process of constructing their understanding of concepts [1,2].

Under the traditional lecture-based teaching model, Juliane [2] described students are primarily passive recipients of the teacher's knowledge transfer, lacking opportunities to actively participate and construct concepts. This often results in low motivation and classroom participation, ultimately leading to unsatisfactory learning outcomes. Faced with this challenge, the educational community is encouraging teachers to actively try to use more flexible, interactive, and hands-on modeling teaching strategies for teaching biological concepts to improve students' learning motivation and class participation so that students can truly understand and apply biological concepts in practical activities [3].

1.2. Modeling Teaching Strategies

In recent decades, researchers and educators have sought to improve the effectiveness of teaching biology concepts through new methods. Traditional narrative-style teaching has been shown to have a limited impact on deep understanding and motivation to learn[2]. In response, model-building instruction has emerged as a promising alternative, garnering increasing attention from researchers. A recent study by Metz et al. [4] provided modeling can facilitate the visualization of complex biological concepts, encouraging students to actively engage in the formation of new ideas through the use of models. This approach enables deeper analysis of the underlying concepts and supports the extension of ideas towards new applications. By integrating the process of "modeling" into the analysis of concepts, students gain a more complete understanding of the concept's connotations and possibilities. This develops students' scientific thinking and enhances the effectiveness of high school biology concept teaching. The instruction of model construction emphasizes students' ability to improve their mastery and understanding of knowledge by constructing models themselves. By manipulating and observing the model, students can gain a more intuitive understanding of abstract biological concepts and enhance their motivation and interest in learning.

In addition, model-building teaching is supported by a sound theoretical foundation. According to the theory of cognitive constructivism, learning is an active and constructive process. Students construct and comprehend new concepts by integrating new knowledge with their existing experiences and ideas. Model-building instruction aligns with this theory, as it provokes student reflection and creativity through the construction of models, which in turn transform theoretical biology concepts into tangible, manipulable forms [4].

Godfrey-Smith’s [5] Research indicates that utilizing model-building instruction as a teaching tool provides notable benefits in the high school biology classroom. It was determined that students were able to better comprehend and apply biological concepts when taught through modeling. Additionally, their learning interest and active participation increased noticeably, further enhancing their exploration and grasp of biological concepts.

Therefore, when teachers teach concepts, they can create real-world situations or activities and employ problem-driven modeling techniques. Koponen [3] explained this approach enables students to develop scientific thinking through the process of problem-solving, where they compare, analyze, deduce, abstract, generalize, and more. Piaget, a Swiss psychologist, also contends that the true aim of education is not to expand knowledge, but to create an environment where pupils can investigate independently and actively acquire knowledge.

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In the work, an educational action research study will be conducted to explore the practical application of the cognitive context-based modeling teaching strategy in teaching high school biology concepts. The study aims to compare the teaching effectiveness of this approach with that of the previous traditional lecture-based teaching strategy, with the hope of enhancing students' motivation and participation in the biology learning process. The results and discussion of this action research are anticipated to establish an empirical foundation for enhancing the teaching of biology concepts in high schools and yield insights for educational research in schools.

2. Methodology

The target population of this educational action research is 57 students in the class taught by the teacher, who are recruited as participants through publicity. Next, teachers design and implement a classroom practice of modeling teaching. By comparing the current cognitive situation-based modeling teaching with the previous traditional lecture-based teaching in mobilizing students' learning motivation and classroom participation, the actual teaching effect of modeling classrooms is evaluated.

2.1. Overview of Action Research

Educational action research is a research method based on educational practice, which aims to improve the effectiveness of educational practice and promote the professional development of educators. Mertler [6] argued it combines research and practice, generates educational reflection through the researcher's practical actions, and promotes the development of the educational environment and learners through the improvement of practice.

Educational action research is usually carried out by educators, educational institutions, or scholars, who aim to solve problems encountered in educational practice and promote the reform and improvement of education and teaching through systematic and reflective actions.

2.2. Models of Action Research

In educational action research, there are many different models to choose from, such as: cyclical action research model, collaborative action research model, evidence-based action research model, etc. This study adopts the cyclical action commonly used by educators' Research model.

The cyclical action research model emphasizes circularity, and researchers continuously improve educational practice through reflection and adjustment. Researchers first define goals, then design and implement educational action plans, collect, and analyze data, and finally reflect and improve based on the results. Ernest Stringer [6], in his action research interactive spiral, describes action research as a "simple but powerful framework" consisting of routines of "observe, think, and act" (p.8). At each stage, participants observe, reflect, and then take some action. This action takes them to the next stage (see Figure 1).

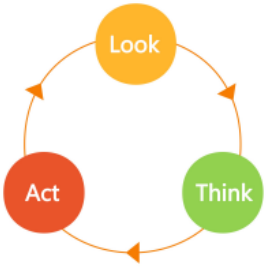

Figure 1: Stringer's Action Research Interacting Spiral [6]

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2.3. The Significance of Action Research in Education

Action research in education offers numerous benefits, including enhancing the quality of educational practices, promoting professional development among educators, fostering cooperative educational communities for shared learning, generating practical knowledge, and supporting individualized education. It provides a powerful framework and methodology for educational improvement and innovation.

This research facilitates the improvement of the educational process and teaching effectiveness by thoroughly understanding and addressing problems encountered in actual educational practices. With the implementation of action research, educators can gain insight into students' needs and issues, leading to the development of more effective teaching strategies.

Geraldo [7] indicated action research in education motivates educators to reflect on their teaching practices, educational philosophies, and professional development. This process enables educators to recognize areas for improvement in their practices and stimulates a willingness to explore and improve. By reflecting and conducting research, educators can continuously develop and improve their educational professional skills.

Action research in education encourages cooperation and participation between teachers, students, and other stakeholders in forming educational communities. Action research often involves active participation and cooperation from teachers, students, and other stakeholders in collectively addressing educational problems and improving practices. This cooperative and co-learning environment helps promote the formation and development of educational communities.

Action research in education combines theoretical knowledge with practice to generate and apply knowledge effectively. By conducting research and reflecting on practice, educators can validate and adjust theories in practice while generating new knowledge specific to educational contexts and issues.

Action research in education facilitates personalized education based on actual data and feedback. By gathering and analyzing data, education practitioners can better understand student needs and differences and adjust and personalize educational practices accordingly. Such a process leads to the implementation of teaching methods and resources that are more responsive to student needs, improving student learning outcomes and satisfaction [6,7].

3. The Educational Action Research Process

3.1. Target Group

The target group for this educational action research was convenience sampling, which recruited a group of senior high school students, all from the teacher's class, consisting of 29 males and 28 females, who had previously been in a traditional lecture-based classroom model for learning biology concepts.

3.1.1. Sampling

These students had been learning biology concepts in a situation where the teacher was directly explaining or demonstrating and the students were passively memorizing and taking notes to pass exams before the teacher shifted to a modeling teaching strategy.

Therefore, before conducting the action research, a questionnaire was administered to these target students to gain a complete understanding of the learning background of these 57 students to better conduct the subsequent research. The content of the questionnaire was self-constructed to serve the following three purposes: (1) to assess the student's current motivation (through the students' pre-study); (2) to collect the deep-rooted reasons for the student's inability to correctly grasp a biology

DOI: 10.54254/2753-7048/49/20231809

concept; (3) to investigate the students' satisfaction with the effectiveness of learning of biology concepts.

3.1.2. Analysis of Students' Questionnaire Data

All 57 students participated in the questionnaire survey, of which 61% were not satisfied with the effectiveness of their learning of biological concepts in the traditional lecture classroom, and 14% of them indicated that they faced obstacles in learning biology concepts that they did not understand. Only 26% of students were satisfied with their learning outcomes.

Then, the underlying reasons for students' inability to grasp a particular biological concept were further analyzed, and it was found that there were four main reasons: (1) students forgot the concept when doing problems; (2) students could not understand the concept through the instructor's explanations; (3) students could not disassemble the key words of the concept; and (4) students could not apply the concept to solve the problem when solving the problem (see Figure 2).

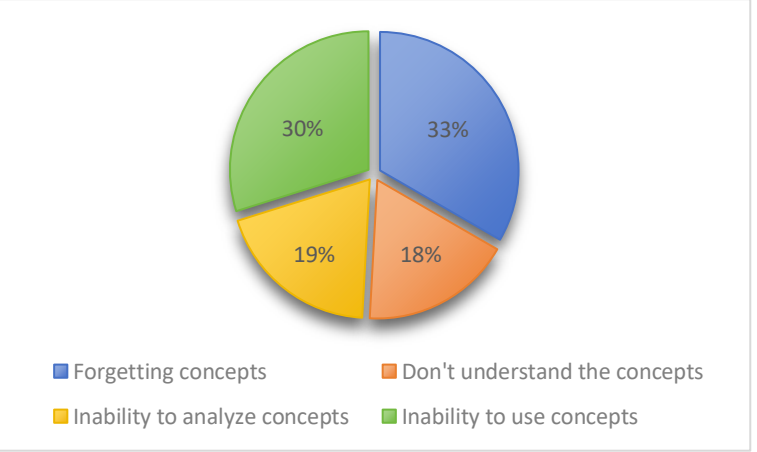

Figure 2: The underlying cause of the failure to grasp a biological concept

3.2. Identifying the Problem

Based on the above findings of students' academic background, this study urgently wants to carry out the cognitive context-based modeling teaching strategy to improve the actual effect of students' conceptual learning in senior high school biology and to compare the differences between the traditional lecture classroom and the conceptual modeling classroom in terms of motivation and classroom participation. After the class, the teacher will also conduct personal interviews to find out the students' attitudes and evaluations of the contextual cognition-based modeling teaching strategy.

3.3. Planning Action

In this phase, the teacher will carefully design a cognitive context-based modeling classroom. The teaching content of this lesson is "ATP, the energy currency of cells", which shows how to help students construct abstract biological concepts through conceptual splitting and creating contexts[8,9].

The core biological concept of this section in the General High School Biology Curriculum Standards (2017 Edition) is that ATP is the direct energy substance that drives cellular life activities. To construct this concept, three conceptual systems need to be constructed first: (1) ATP is a high-energy phosphate compound; (2) Types of energy substances; (3) Reasons why ATP is a direct energy substance.

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Next, take conceptual system 1 as an example to see how to help students understand that ATP is a high-energy phosphate compound through modeling teaching strategies.

3.3.1. Creating a Real Situation Associated with ATP

Teachers play the video of actor Xu Zheng participating in the Ice Bucket Challenge to briefly introduce the disease of ALS and bring out ATP. The introduction of the Ice Bucket Challenge as a social hotspot creates a real problem situation for students, which can quickly stimulate students' curiosity.

3.3.2. Construct a physical model to simplify the structure of ATP

3.3.2.1. Getting to Know the Structure of ATP

Let students read the textbook and think: (1) What is the Chinese name of ATP? (2) What are the parts of the chemical structure of ATP? (3) What are the elements of ATP?

3.3.2.2. Construct a Model of ATP Structure

Imitating the structural model diagram of nucleotides, students try to represent the parts of ATP with different diagrams. Groups of students discuss specific ways of constructing and drawing a structural model of the ATP molecule on paper, after which they present it to the group for sharing and listen to the suggestions of their peers and the teacher to make corrections to the structural model of the ATP molecule.

3.3.2.3. Simplify the ATP Structure

Guide students to simplify the graphical model into a letter model, and finally summarize the structure of ATP with the "123" mnemonic method. That is 1 molecule of adenosine, 2 high-energy phosphate bonds, and 3 phosphate groups.

3.3.3. Constructing Concept 1: ATP is a High-energy Phosphate Compound

Teachers guide students to analyze the characteristics of the structure of ATP and explain why ATP is a high-energy phosphate compound to understand Concept 1.

3.4. Acting

3.4.1. Pre-Class Preparation

Before class, students were invited to participate in a questionnaire to determine the frequency of their prior study of new biology concepts. Pre-study frequency is an important factor that affects student motivation and engagement in class. This information helps teachers assess student motivation and adjust their teaching strategies accordingly.

One week before implementing the modeling instructional class, the teacher observed the target students' classroom engagement under the previous traditional lecture-based instructional approach. The teacher used a self-developed observation scale to assess the effectiveness of the teacher's guidance, the students' response status, and the quality of their responses. The final measurements from the observation scale can be used to evaluate the effectiveness of the instructional strategy and comprehensively assess learning outcomes.

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3.4.2. In-Class Implementation

In the lesson about "ATP, the energy currency of cells", the teacher informed students that a modeling instructional strategy would be used to help them understand three conceptual systems about ATP: (1) ATP is a high-energy phosphate compound; (2) Types of energy substances; (3) Reasons why ATP is a direct energy substance. The teacher hopes students will understand and apply the concept more deeply through independent conceptual modeling in a specific problem situation[10,11].

At the back of the classroom, eight biology teachers from the school were invited to observe the lesson using a classroom engagement observation scale. Each teacher was assigned six students to observe and score based on the effectiveness of the teacher's guidance, the student's response status, and the quality of their responses. Through the measurement data of the student's classroom engagement scale, teachers can compare student engagement levels under different teaching strategies.

3.4.3. Post-Class Evaluation

After the lesson, students were again invited to participate in a questionnaire to assess their intrinsic motivation to learn if it had increased, and whether they were willing to make a change to do so after experiencing a student-centered, concept-building classroom.

The teacher conducted a multi-factor variance analysis to test for significant differences between the classroom engagement measurement of students who were in the traditional lecture-based instructional approach and now in the ongoing cognitive context-based modeling instructional strategy [12]. This was to see if the modeling instructional approach was truly effective in increasing student engagement in the classroom.

Additionally, the instructor interviewed six students randomly about their attitudes and evaluations of the contextual cognition-based modeling instructional classroom. This was to find out if students found the classroom model effective in improving their learning of biology concepts.

3.5. Results and Discussion

Firstly, the results of the questionnaire survey comparing the frequency of students learning new concepts in biology before and after the implementation of the cognitive situation-based modeling teaching strategy showed that after the implementation of the modeling teaching strategy, the frequency of students previewing new concepts increased, and the number of students who consciously always and regularly previewed new concepts increased from 20 to 38 (see Figure 3). The increase in the frequency of previewing means that students are more willing to devote their time to the exploration of new concepts. They will understand the concept in advance and consult some materials. In class, their attention is mainly on the understanding of the concept and the confusion that exists. They will be more inclined to ask some controversial questions. Teachers and students communicate and discuss together. The final results will help correct their cognitive biases on this concept.

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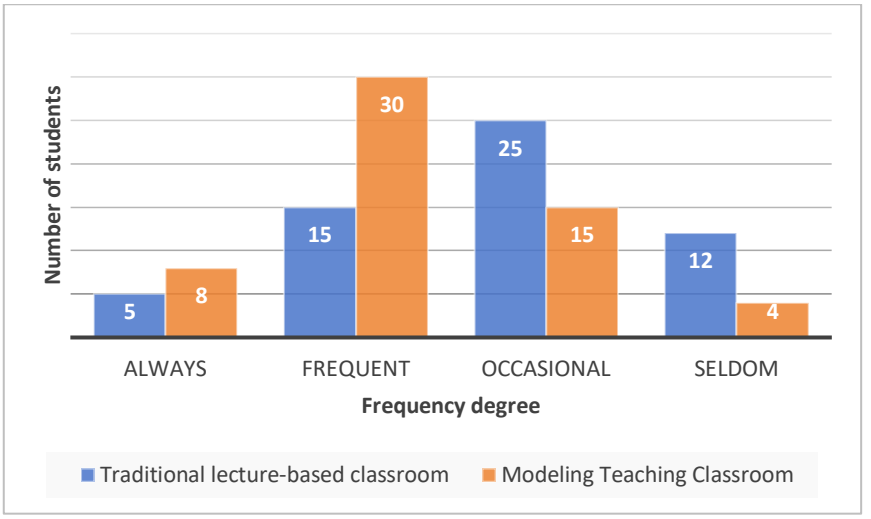

Figure 3: How often students preview new concepts in biology

Secondly, a multi-factor variance analysis [13] was carried out on the measurement data of students' classroom participation observation scale under different teaching strategies before and after, and the results showed that whether it was from the effectiveness of teacher guidance strategies, student response status or student response quality dimensions, all showed significant differences (** $p < 0.01$). From the table below(see Table 1), it can be seen that the average value of the three dimensions of the modeling teaching classroom is significantly higher than that of the traditional lecture-style classroom, which also proves that the modeling teaching classroom based on cognitive situations The participation of students is greatly improved, and students are more willing to actively participate in the real situation created by teachers to think about problems and try to construct their thinking process, to build their cognition of a certain concept. Odenbaugh [7] pointed out that modeling teaching strategies based on cognitive situations tends to place more emphasis on teachers to promote students' active participation and thinking through situation creation. By introducing real cases or stories, role-playing, experimental inquiry learning, group cooperative learning, and other teaching links, can create a positive learning atmosphere, improve students' classroom participation, and promote their in-depth understanding and application of what they have learned.

Table 1: Multivariate analysis of students' classroom participation observation scale data

	Classroom type(Mean ± standard deviation)		*F*	*p*
	Modeling Teaching Classroom(*n*=48)	Traditional lecture-based classroom(*n*=48)		
Validity of the teacher's guidance strategy	4.22±0.59	3.39±0.98	24.031	0.000**
Students' response status	3.72±0.58	2.61±0.86	52.699	0.000**
Quality of students' answers	3.15±0.76	2.65±0.99	7.354	0.008**

* $p<0.05$ ** $p<0.01$

Finally, the instructor used the after-school time to randomly interview six students about their feelings and evaluations of the cognitive context-based modeling instruction classroom. Overall, the students were satisfied with the learning of abstract concepts in biology under the implementation of

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the modeling teaching strategy, and they expressed their hope that this model would be continued in future classes. They no longer considered biological concepts as boring but showed great interest and thought that this biological knowledge was helpful for their real life. Shown below are some of the students' comments:

"This classroom model is very novel, I found that biology is so interesting".

"I hope that the teacher will continue to use this mode of class, I feel that learning biology concepts is not so difficult now".

"In the past, I used to learn biology concepts by rote memorization, and I couldn't apply them, but now I try to understand them by modeling, and it's much easier to learn".

"This model gives me more time to think and share, I feel like I'm involved in the classroom".

4. Conclusion

The important conclusion of this action study is that the use of cognitive context-based modeling teaching strategies in high school biology concept teaching classrooms can significantly improve students' pre-class preview frequency and classroom participation. Teachers actively participate with students by carefully designing interesting and practical learning situations. Students are more willing to think about problems, express opinions, propose solutions, and communicate and discuss with their peers in such classroom activities to actively construct their cognition of this concept. In this process, the role of teachers is to guide and help, and students are the main body of learning.

The results of this action study confirm that the modeling teaching strategy based on constructivism theory can greatly improve many drawbacks of traditional lecture-based classrooms. It advocates the interaction and cooperation between teachers and students, and teachers create real and specific perceptual situations for students. Encourage students to think and communicate actively. This can prevent students from rote memorization because they do not understand concepts, and in the end, they still will not apply concepts to solve practical problems, resulting in students' fear of difficulties in the subject.

After the implementation of the modeling teaching strategy based on cognitive context, it has achieved phased success. In the future, it is planned to be popularized and applied in the biology classroom of our school, and it is also trying to be implemented in other disciplines. However, there are inevitably some controversies in the results of this action study. For example: (1) The study only selected students from one class in the third year of high school in our school as participants, and the results may not be universal; (2) In the process of action research, the subjective factors of the researcher may have an impact on the results; (3) The time for action research to be carried out is limited, and the experimental data in a short period, time may not fully explain the conclusions, and there are objections. Also, under the modeling teaching strategy, teachers are not precise enough to create specific teaching links.

Therefore, in the future, we will continue to work on improving the application of modeling teaching strategies based on cognitive context in biology classrooms to achieve better teaching effects. Although this research has certain limitations, it is undeniable that it provides a valuable reference for improving the educational practice research of high school biology concepts.

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