International Journal of Education (IJE) Vol.01, No.04, November 2024.

Experimental Teaching Practice Based on the History of Biology——Taking the Infection of E. coli by T2 Phage as an Example

Li Tong

Department of Baotou No.6 High School, Inner Mongolia Autonomous Region, China.

ABSTRACT

This article takes the T2 phage infection of E. coli experiment by M. Chase and A.D. Hershey as an example to analyze how the history of biology can develop students' scientific thinking, enhance their problem-solving abilities, and improve their collaborative and communication skills, preparing students to become talents that adapt to the progress of society and the development of the era.

KEYWORDS

High School Biology, History of Biology, Experimental Teaching

1. INTRODUCTION

Biology is a natural science, and the development of natural sciences is inseparable from the exploration of scientists; it is also a history of scientific inquiry. The history of biology is a branch of the history of natural science development. Each discovery in life sciences has gone through processes such as careful observation, meticulous experiments, rigorous analysis, in-depth reasoning, and strict verification by scientists. It represents the progress of human scientific thought, the development of science and technology, and the evolution of methods. Learning about the history of biology not only allows students to understand the emergence and development of knowledge but also stimulates their interest in learning and their curiosity to explore the unknown world.

Many significant discoveries in the history of biology shine with the extraordinary creative thinking of scientists and the result of the comprehensive application of various scientific research methods. For example, in the exploration of photosynthesis, scientists successfully investigated the changes in substances during photosynthesis through isotope labeling methods (M. Calvin & A.A. Benson, 1948). Watson and Crick constructed the DNA double helix structure model by analyzing the X-ray diffraction patterns of DNA (J.D. Watson & F.H.C. Crick, 1953). Meselson and Stahl used equilibrium density gradient centrifugation to prove that DNA replicates semi-conservatively(Meselson, Matthew & Franklin W. Stahl, 1958). Mendel's ability to discover the two major laws of inheritance was related to his careful choice of experimental materials and scientific observation and analysis methods. When observing, he focused on one pair of traits amidst complex hybrid phenomena, ignoring other traits for the time being, which greatly simplified the research subject. In particular, his introduction of mathematical statistical methods into biological research was an innovation that surpassed his predecessors (Scott Abbott & D.J. Fairbanks, 2016).

2. Cultivating Students' Scientific Spirit Based on the History of Biology

The "High School Biology Curriculum Standards (2017 Edition)" states that learning about the nature of science helps students establish biological concepts, understand the characteristics of the generation of scientific knowledge, grasp the features of natural sciences, and use this to distinguish between science and non-science in real life, thereby promoting the achievement of core literacy in the biology discipline. The history of biology not only truly records the development process of biological sciences but also elaborates on the background and laws that formed this process(Magner, 2002). The history of biology should explore its intrinsic value in experimental teaching, making it an effective way and means to cultivate students' spirit of seeking truth, research, cooperation, inquiry, skepticism, and innovation.

2.1. Cultivating a Spirit of Seeking Truth

In the history of biology, scientists objectively observe the morphological structures of organisms and study their physiological characteristics. They diligently conduct biology experiments and pragmatically analyze the observed experimental results. This spirit of being down-to-earth and seeking truth is an exemplary model for students to learn from. For example, Gregor Mendel, the founder of genetics, spent 8 years using peas as his experimental material, tirelessly conducting a vast number of experiments(2016). Although he was an abbot, he was not influenced by religion and always maintained a pragmatic scientific attitude towards the statistical analysis of the data obtained from his experiments. Ultimately, he revealed the two major laws of inheritance and became known as the "Father of Genetics." Charles Darwin, with his relentless perseverance, completed a 5-year global voyage, making observations and analyses based on factual evidence(J. Browne, 2023), which led to the monumental work on species evolution, "On the Origin of Species."

2.2. Cultivating a Spirit of Research

The tenacious perseverance and fearless spirit of inquiry in scientists serve as exemplary models for students. For instance, Sumner, despite his physical disabilities and poor health, worked in a rudimentary basement for nine years and ultimately succeeded in extracting urease crystals from jack-bean seeds (R.D. Simoni, R.L. Hill & M. Vaughan, 2002). The renowned French entomologist Henri Fabre observed wasps for 20 years and dung beetles for 40 years, leaving behind a valuable treasure trove of knowledge on insect behavior (Jean Henri Fabre, 1998).

2.3. Cultivating a Spirit of Cooperation

A sense of cooperation is a fundamental quality that modern individuals should possess. Some of the great discoveries and famous inventions in the history of biology are often the result of sincere collaboration among scientists. For example, Watson and Crick, who were of different nationalities and had distinct personalities, built upon the research on the structure of DNA molecules by Chargaff, Franklin, Wilkins, and others (1953). Together, they collaborated to propose the double helix model of DNA, which is a milestone in the history of biology and holds epoch-making significance.

2.4. Cultivating a Spirit of Inquiry

In the teaching of the history of biology, it is essential to guide students to follow the thought process of scientists and simulate their journey of inquiry to perceive the process of knowledge discovery, which is crucial for cultivating students' spirit of exploration. For example, taking the discovery of plant auxins as the main thread of scientific history, after learning each classic experiment, students are guided to scientifically reason about the experimental phenomena (Jerry D. Cohen & Lucia C. Strader, 2024). On this basis, the next classic experiment is introduced. As students revisit the process of discovering auxins, they develop their ability to explore.

2.5. Cultivating a Spirit of Skepticism

Scientific knowledge is not a flawless "absolute truth"; it evolves with ongoing research. In the teaching of the history of biology, it is important to encourage students to ask questions and challenge assumptions. For instance, the founders of the cell theory, Schleiden and Schwann, initially proposed that "new cells arise from pre-existing cells." However, Virchow did not blindly follow authority and boldly questioned this idea. Building on Nageli's work, he summarized that "cells arise from the division of existing cells," which allowed cell theory to be refined and developed (Paolo Mazzarello, 1999).

2.6. Cultivating a Spirit of Innovation

Every scientific invention and creation is inseparable from the innovation in scientists' thinking, technology, or methods. In the teaching process, making full use of the history of science to guide students can cultivate their awareness of innovation while they acquire knowledge. For example, based on E. Wertherimer experiments, E.H. Starling and W.M. Bayliss boldly innovated the experimental method and discovered the first hormone – secretin (Graham Dockray, 2005); Hershey and Chase innovated the experimental method and, through experiments with phages infecting bacteria, proved that DNA is the true genetic material (Chase & Hershey, 1952). These historical examples demonstrate how innovation has driven scientific breakthroughs and can inspire students to think creatively and critically.

3. The Experimental Teaching Process Based on the History of Biology

3.1.Historical Facts Introduction to Stimulate Interest in Learning

Considering the academic characteristics of first-year high school students, the true history of biology can not only allow students to understand the process of knowledge discovery and development but also stimulate their profound interest in learning and their curiosity to explore the unknown world. Teachers can use the history of biology to guide students to think like scientists, to personally experience the process of inquiry, and to reach the specific thought process of drawing conclusions.

3.2.Building Models to Cultivate Concepts of Life

The selection of experimental materials is a necessary factor for the success of an experiment. Why did scientists like M. Chase choose T2 phage as the experimental material and how did they cultivate it (1952)? Teachers guide students to consult relevant materials, analyze the structure and composition of the T2 phage, and clarify that the T2 phage is a virus that lives parasitically and cannot live and reproduce independently, and its host is E. coli. Students will understand that they need to cultivate T2 phage by cultivating E. coli, thus selecting appropriate materials and tools: transparent buckets, stirring rods, scissors, transparent plastic bottles, syringes, red tape, red and blue metal wires, etc., to build a model of E. coli and the parental and progeny T2 phages. Teachers demonstrate the process of T2 phage infecting E. coli to students through multimedia animations and help them understand the principle of the experiment: The T2 phage adsorbs onto the surface of E. coli, injects its own DNA into the E. coli, and under the action of its own DNA, uses the substances inside E. coli to synthesize its own DNA and proteins and assemble into progeny T2 phages. When the phage multiplies to a certain extent, the E. coli lyses and releases a large number of progeny phages.

Figure 1 Materials and Tools for Experiments

Figure 2 DNA of E. coli and T2 phage

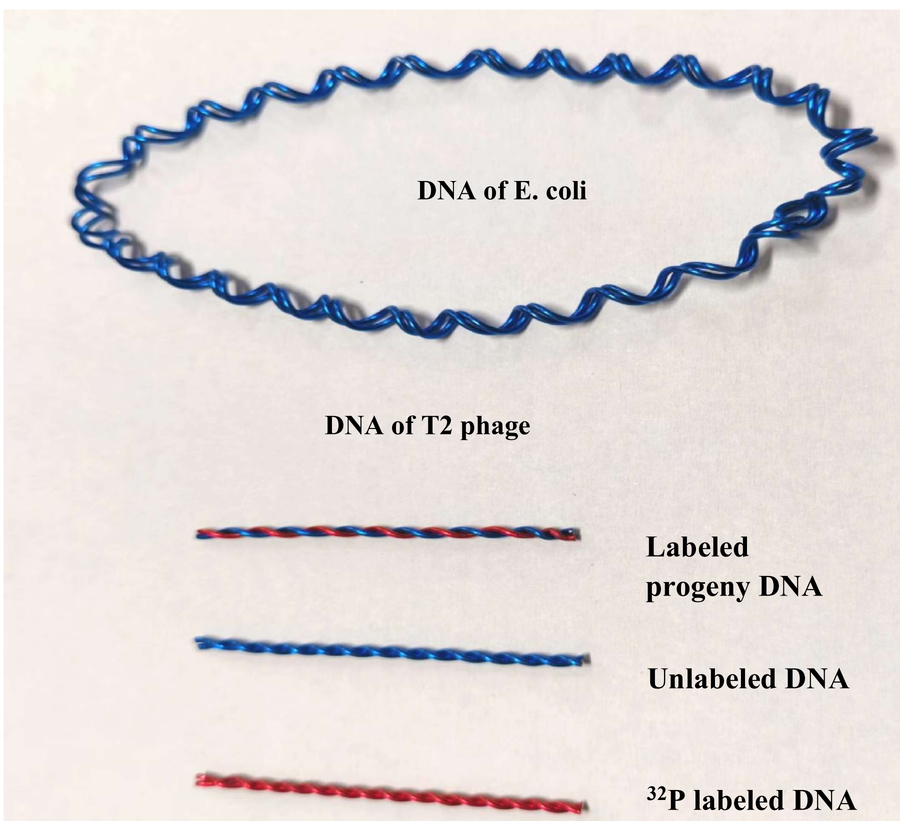


Figure 3 and labeled phage model

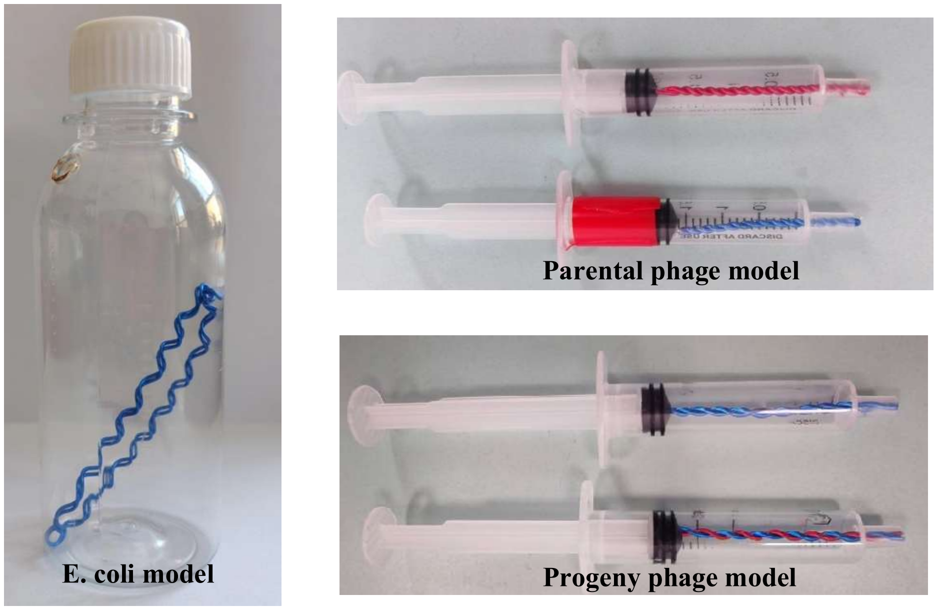
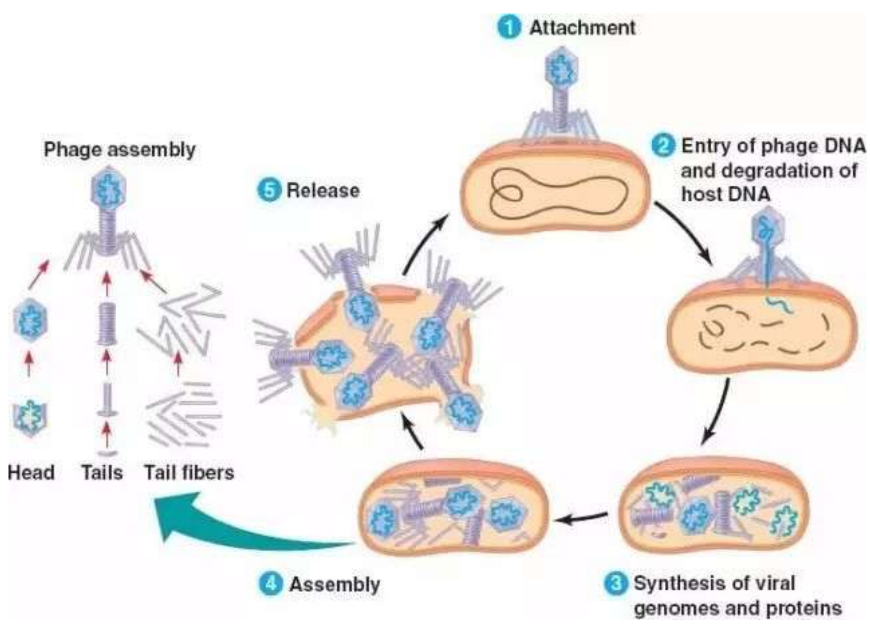


Figure 4 T2 phage infection of E. coli process



3.3.Designing Experiments to Cultivate Scientific Thinking

Building upon Avery's experiment, students can easily come up with the idea of separating the DNA and protein coat of the T2 phage to infect E. coli separately and then observe the phenomena (Avery, MacLeod & McCarty, 1944). How can one ensure the complete separation of the T2 phage's DNA and protein coat? Teachers guide students to recall the experiment of Kamen and Ruben and study the textbook, which mentions the use of "isotopic labeling method" as the experimental technique. Then, based on the analysis of T2's composition and the elemental composition of DNA and proteins, teachers guide students to consider which elements to label, which leads to the decision to label phosphorus (P) and sulfur (S) (Magner, 2002). The teachers then continue to ask: How can these two elements be labeled in T2 phages? By cultivating T2 phages in a culture medium containing radioactive isotopes ^{32}P and ^{35}S? Students have already learned that viruses cannot live and reproduce independently and cannot be directly cultured on a culture medium, and thus they can deduce that: To label T2 phages, one must first cultivate E. coli in a culture medium containing radioactive isotopes ^{32}P and ^{35}S, and then cultivate T2 phages to obtain two types of T2 phages, one labeled with ^{32}P and the other with ^{35}S.

3.4.Collaborative Experiments to Cultivate the Spirit of Science

After the experiments are designed, students are divided into groups of 8, with 4 simulating the infection of E. coli with T2 phages labeled with ^{32}P, and the other 4 simulating the infection with T2 phages labeled with ^{35}S. During the experiment, students contemplate: What is the impact of the duration of incubation on the infection of E. coli by T2 phages?

Why is stirring necessary before centrifugation? What are the purpose and outcome of centrifugation? Teachers guide students to learn how to record the experimental process, observe, and analyze the results. The experimental results of each group are shown in Table 1.

Table 1. Radioactivity results of each group.

Group			Radioactivity
1	^{32}P	supernatant	Non-radioactive.
		precipitate	Radioactive.
	^{35}S	supernatant	Radioactive.
		precipitate	Non-radioactive.
2	^{32}P	supernatant	Non-radioactive.
		precipitate	Radioactive.
	^{35}S	supernatant	Highly radioactive.
		precipitate	Low radioactive.
3	^{32}P	supernatant	Non-radioactive.
		precipitate	Radioactive.
	^{35}S	supernatant	Radioactive.
		precipitate	Non-radioactive.
4	^{32}P	supernatant	Non-radioactive.
		precipitate	Radioactive.
	^{35}S	supernatant	Radioactive.
		precipitate	Non-radioactive.
5	^{32}P	supernatant	Non-radioactive.
		precipitate	Radioactive.
	^{35}S	supernatant	Radioactive.
		precipitate	Non-radioactive.
6	^{32}P	supernatant	Highly radioactive.
		precipitate	Low radioactive.
	^{35}S	supernatant	Radioactive.
		precipitate	Non-radioactive.

By observing the results, students find that in the ^{32}P-labeled group, the radioactivity in the supernatant is low, while it is high in the pellet; in the ^{35}S-labeled group, the radioactivity in the supernatant is high, while it is low in the pellet. By comparing the results of each group, students can conclude that the genetic material of T2 phages is DNA.

3.5.Discussing and Analyzing Experimental Errors

Reaching the final conclusion does not mean the end of the experiment. Teachers should also guide students to think, discuss, and analyze any experimental errors that occurred in each group. For example, in the 2nd group with ^{35}S labeling, there is a high level of radioactivity in the supernatant, which theoretically should not have radioactivity in the pellet. Why is there radioactivity in the pellet? Students discuss and analyze: After the ^{35}S-labeled T2 phages infect E. coli, they were not sufficiently stirred before centrifugation, which caused some of the protein coats of the T2 phages to not separate from the E. coli and, after centrifugation, sank to the bottom with the E. coli, resulting in radioactivity in the pellet. Therefore, to avoid experimental errors, it is important to stir thoroughly before centrifugation. In the 6th group with ^{32}P labeling, the radioactivity in the supernatant is high, and the radioactivity in the pellet is low, which is the opposite of the theoretical result of almost no radioactivity in the supernatant and high radioactivity in the pellet. Why is that? Students analyze: The ^{32}P-labeled T2 phages may not have been mixed and cultured with E. coli for a sufficient duration before centrifugation, meaning the T2 phages did not fully infect the E. coli, and after stirring and centrifugation, there were still many ^{32}P-labeled T2 phages in the supernatant; or it could be that the culture time was too long, and the progeny T2 phages were released from the E. coli, both of which could cause this outcome. Therefore, to avoid this error, strictly controlling the incubation time is one of the factors for the success of the experiment.

4. SUGGESTIONS

In high school biology laboratory teaching, it is essential not only to cultivate students' scientific spirit but also to develop their core biological literacy. This requires teachers to strengthen their study and research of the new curriculum standards and teaching materials, explore the history of biology within the textbooks, and make full use of historical materials to guide students to actively participate, think deeply, and analyze rationally. This approach helps to develop students' scientific thinking, enhance their problem-solving abilities, and improve their communication and collaboration skills. By doing so, the educational goals and direction of subject literacy can be truly achieved in laboratory teaching, preparing students to become talents that adapt to the progress of society and the development of the times.

References

[1] M. Calvin & A.A. Benson, (1948)"The Path of Carbon in Photosynthesis", *Science*, Vol. 107, No. 2784, pp476-480.

[2] J.D. Watson & F.H.C. Crick, (1953) "Molecular Structure of Nucleic Acids: A Structure for Deoxyribose Nucleic Acid", *Nature*, Vol. 171, pp737-738.

[3] Meselson, Matthew & Franklin W. Stahl, (1958) "The Replication of DNA in Escherichia Coli", *Proceedings of the National Academy of Scences*, Vol. 44, pp671-682.

[4] Scott Abbott & D.J. Fairbanks, (2016) "Experiments on Plant Hybirds by Gregor Mendel", *Genetics*, Vol. 204, No. 2, pp407-422.

[5] J. Browne, (2023) "Darwin's First Writings: From the Beagle Voyage to His Transmutation Notebooks(1837-1839) and Essay(1844)", *Springer*, Vol. 34, pp81-97.

[6] R.D. Simoni, R.L. Hill & M. Vaughan, (2002) "Urease, the First Crystalline Enzyme and the Proof That Enzymes Are Proteins: the Work of James B. Sumner", *Journal of Biological Chemistry*, Vol. 277, No. 35, E1-E2.

[7] Jean Henri Fabre, (1998) *Fabre's Book of Insects*, Book, Dover Publications.

[8] Jerry D. Cohen & Lucia C. Strader, (2024) "An auxin research odyssey: 1989-2023", *The Plant Cell*, Vol. 36, No. 5, pp1410-1428.

[9] Paolo Mazzarello, (1999) "A unifying concept: the history of cell theory", *Nature Cell Biology*, Vol. 1, E13-E15.

[10] Graham Dockray, (2005) "Gastrin: old hormone, new functions", *Springer*, Vol. 449, pp344-355.

[11] A.D. Hershey & M. Chase, (1952) "Independent functions of viral protein and nucleic acid in growth of bacteriophage", *The Journal of General Physiology*, Vol. 36, No. 1, pp39-56.

[12] O.T. Avery, C.M. MacLeod & M. McCarty, (1944) "Studies on chemical nature of the substance inducing transformation of Pneumococcal types", *The Journal of Experimental Medicine*, Vol. 79, No. 2, pp137-158.

[13] Lois N. Magner, (2002) *A History of the Life Sciences, Revised and Expanded*, Book, Taylor and Francis; CRC Press.