Biology: Life as a System and Evolution as a Logic

Aleksandr Kleymenov

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Author: Aleksandr Kleymenov
ORCID: 0009-0004-9404-2400
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Abstract

In this article, I show how biology as a school subject can become a unique space for the development of mental mechanisms - provided that we stop reducing it to memorizing terms and memorizing classifications. Drawing on the CCFP model presented in the previous articles of the module, and on current research from 2024-2025 in the field of biology education, I justify that biology possesses an exceptional potential for the development of systems thinking, the construction of causal relations, forecasting and strategic thinking, critical thinking, emotional intelligence, information search and analysis, as well as spatial imagination and eloquence. I propose concrete examples of lessons and tasks in which evolutionary logic, ecological modeling, experiment, and reasoned discussion serve not as an end in themselves but as a means of developing thinking. I pay particular attention to the diagnosis of progress and the connection of subject instruction with the infrastructure of the school - the biology laboratory, the greenhouse, and the ecological trail. I also justify that the restructuring of the teaching of biology is not merely a methodological question but a strategic task: it is precisely through biology that the cognitive apparatus capable of understanding complex, self-organizing, evolving systems is formed - the type of thinking that is necessary for comprehending the phenomenon of life, including the nature of consciousness.

Keywords: biology, mental mechanisms, systems thinking, evolutionary logic, causal thinking, forecasting, critical thinking, diagnosis, infrastructure.

A Tree That Remembers Its Ancestors

I will begin with a statement that may seem controversial, but I consider it fundamental. Biology at school is not a subject about how to memorize the names of organs and taxonomic units but a subject about how life is structured, how systems arise, develop, and evolve, and how we ourselves are part of these systems. It is a subject through which a person learns to understand complexity - not as chaos but as organized complexity in which every element is connected to every other. Of course, knowledge of terms and the ability to classify is important. But it is an instrument, not an end. The end is the capacity to think systemically; the capacity to understand evolutionary logic; the capacity to forecast the consequences of changes in biological systems; the capacity to evaluate information critically; the capacity to understand oneself and others as living beings [1; 5].

Here it is appropriate to recall Darwin, who at the end of *On the Origin of Species* wrote that there is a grandeur in this view of life. He saw in the tree of life not merely a scheme of kinship but a history. Each branch is millions of years of trials, mistakes, accidents, and necessity. Each leaf is a being that managed to survive. And we humans are not the crown of creation but one of the branches. A young, recent branch, but one that has already managed to ask the question: what is life? And this is not a question about terms. It is a question about how meaning arises from chemistry. How experience arises from cells. How consciousness arises from evolution. And biology is the only subject that dares to ask this question. Not because it has the answer. But because it has the courage to admit that the answer does not yet exist.

As I already showed in the first article of this series [5], the principle of the dual purpose of a lesson means that every biology lesson must simultaneously solve two tasks: the subject task - the mastery of biological content, and the meta-subject task - the development of mental mechanisms. These tasks do not contradict each other - on the contrary, they mutually reinforce each other. It is important to emphasize: biology creates the conditions of possibility for the

development of mental mechanisms but is not their sufficient cause. Memorizing terms or drawing diagrams by itself will not develop systems thinking. Development occurs only through specially organized pedagogical activity, where the teacher acts as a facilitator and architect of the cognitive apparatus [5; 6]. Research confirms: in the contemporary world, where students encounter an enormous amount of information, the ability to analyze, evaluate, and correctly interpret information becomes increasingly important [8]. Biology is an ideal subject for the development of this ability, since it requires an understanding of complex, multidimensional systems. Contemporary research shows that approaches such as the STEM-based flipped classroom can effectively improve students' critical thinking and biological literacy [8]. And the 5C method not only improves conceptual understanding but also promotes critical thinking, collaboration, and the use of learning strategies [9].

But I want to go further and show how each of the eleven mental mechanisms can be developed through the teaching of biology - and how this changes the very approach to the subject. Biology is not merely a natural science among others. It is the science of life, of the most complex systems in the Universe. This is precisely why biology, in my view, is the key subject for the formation of the communicative-cognitive framework of personality [1]. Moreover, the restructuring of the teaching of biology is not merely a methodological question. It is part of that historical necessity of the change of the pedagogical paradigm of which I wrote in articles [3] and [4]. The industrial school reduced biology to a set of terms and classifications that had to be memorized. But post-industrial society needs people capable of thinking, creating, and adapting - and biology here is the key instrument. As I showed in article [2], subject-centrism is one of the main reasons for the tenacity of the old model. Overcoming this subject-centrism begins with a rethinking of the role of biology in education.

The Whole That Is Greater Than the Sum of Cells

Systems thinking and the construction of causal relations are developed through biology in the most direct and natural way. Biology is the science of systems. An organism is a system of organs. A population is a system of organisms. An ecosystem is a system of populations and their interactions. Understanding biology requires understanding how these systems are structured and how they work. The ability to see how a change in one element of a biological system affects the entire system. The ability to build causal chains from genes to traits, from organism to ecosystem. The teacher must consciously focus attention on the systemic logic of biological phenomena. Not "memorize the structure" but "explain how it works in the system." Not "learn the classification" but "understand how evolutionary connections explain diversity." Research shows that systems thinking is becoming increasingly important in biology education [10]. In the context of ecosystems, for example, systems thinking includes such skills as identifying system organization, analyzing system behavior, and system modeling [11]. However, as an analysis of biology learning tasks shows, the skill of system modeling is often omitted - and this is precisely what needs to be developed [12].

It is like a forest. You can count all the trees. Describe each one. Draw every branch. But until you understand that a forest is not merely the sum of trees, you will not understand the forest. Because a forest is a system in which trees are connected to each other through the mycelium, through shade, through water, and through soil. And if you cut down one tree, this will affect all the others. Even those that are far away. Even those that have not yet grown. So it is in biology. An organism is not the sum of organs. It is a system in which each organ has meaning only in connection with the others. And if you damage one, the entire organism will suffer. And this is the most important thing. Not organs. But connections. Which make organs something more than just organs. And biology teaches one to see these connections. Every day. In every lesson. With every topic. Which is not merely studied. It is connected. And in this lies its strength. And in this lies its beauty. And in this lies its meaning. Which does not end. As biology does not end. As thought does not end. As life does not end.

Forecasting and strategic thinking is a mechanism that biology requires and develops. Biology requires constant forecasting. What will happen to a population if the climate changes? How will a species evolve under the pressure of selection? What will be the consequences of disrupting ecological balance? The ability to foresee the consequences of changes in biological systems. The ability to build forecasts on the basis of evolutionary logic. The use of the POE method - predict, observe, explain. Research shows that the use of the POE learning model effectively improves critical thinking [19]. It is like a doctor who looks at test results and sees not numbers but a disease. They see what will happen if the disease is not treated. They see what will happen if it is treated. And they choose the path. That leads to life. And not to death. So it is in biology. A student who can forecast sees not only what is. They see what will be. And they can choose. What to do. So that it becomes better. And not worse. And this is the most important

thing. Not the forecast. But the choice. Which stands behind it. And which makes you responsible. For yourself. For others. For the world. Which is not alien. But yours. Because you are part of it. And biology teaches this. Every day. In every lesson. With every forecast. Which is not merely made. It is experienced. And in this lies its strength. And in this lies its beauty. And in this lies its meaning. Which does not end. As biology does not end. As thought does not end. As life does not end.

Critical thinking is another mechanism that biology develops in a unique way. Biology gives unique opportunities for the development of critical thinking. Evolutionary theory requires the evaluation of evidence. Ecological research requires the analysis of data. Medical information requires the verification of reliability. The ability to evaluate scientific evidence. The ability to analyze data. The ability to distinguish scientific facts from pseudoscientific claims. The use of models that require argumentation. Research shows that the ADI model significantly improves students' argumentation skills [15]. Argumentation-based instruction significantly improves students' general scientific skills in biology [16]. It is like a judge who considers a case. They do not merely believe one side. They check the evidence. They look for contradictions. They deliver a verdict. And if they make a mistake, they can change their decision. Because they know how to doubt. And a student who knows how to doubt does not take everything on faith. They check. And find the truth. Or, at least, approach it. And this is the most important thing. Not the truth. But the path to it. Which begins with doubt. And ends with understanding. Which is always relative. But always valuable. Because it is yours. Found by you. Checked by you. Understood by you.

The Body That Speaks

Emotional intelligence is a mechanism that biology develops through understanding oneself. Biology is not only the science of other organisms. It is the science of ourselves. Understanding one's body, one's health, and one's place in nature - all of this requires and develops emotional intelligence. The ability to understand oneself as a biological being. The ability to be aware of one's body and its needs. The integration of knowledge about health, anatomy, and physiology with reflective practices. Research shows that the development of critical thinking skills is necessary for students to succeed in studying biology, and this includes understanding oneself [9]. It is like a child who feels for the first time that their stomach hurts. They do not know the word "gastritis." But they know that it hurts. And they say so. And mother understands. And takes them to the doctor. And the doctor understands. And treats them. And the child recovers. So it is in biology. A student who understands their body does not merely know where the organs are located. They know how they work. And how they can help them. Or harm them. And this is the most important thing. Not anatomy. But care. Which begins with understanding. And ends with health. Which is not given. But created. Every day. By every choice. By every thought. And biology teaches this. Not because it is in the curriculum. But because it is in life. And this is the most important thing. Not the subject. But life. Which does not end. As biology does not end. As thought does not end. As the human being does not end. Who knows how to understand. And care. And live.

Information search and analysis is a mechanism that biology requires and develops. Contemporary biology is work with enormous arrays of data: genomic, ecological, and clinical. The ability to find, analyze, and interpret information becomes key. The ability to work with scientific sources. The ability to analyze biological data. The ability to interpret graphs and tables. A research approach, working with real data. Research shows that the development of STEM-based learning materials can effectively promote higher-order thinking in biology education [10]. It is like an archivist who searches for documents in dusty folders. They do not merely find papers. They read them. Compare them. Check them. And only then draw a conclusion. And if they simply take the first paper that comes to hand and say that this is the answer, they are mistaken. And their mistake may cost dearly. So it is in biology. A student who cannot search for information takes the first article that comes to hand. And applies it out of place. And gets an incorrect conclusion. And a student who can search finds several sources. Compares them. Checks them. And only then draws a conclusion. And their conclusion turns out to be correct. Because they did not merely find. They understood. And this is the most important thing. Not information. But understanding. Which comes not from quantity. But from quality. Not from speed. But from depth. And biology teaches this depth. Every day. In every lesson. With every investigation. Which is not merely conducted. It is made sense of. And in this lies its strength. And in this lies its beauty. And in this lies its meaning. Which does not end. As biology does not end. As thought does not end. As life does not end.

Spatial imagination and eloquence are mechanisms that biology also develops. Biology develops spatial imagination through work with anatomical models, three-dimensional structures of cells and tissues, and ecological maps. And

eloquence through the need to explain complex biological concepts, argue for evolutionary conclusions, and present the results of research. The ability to see three-dimensional structures. The ability to explain biological phenomena clearly and convincingly. Working with 3D models, using molecular visualization programs. Research shows that 3D-printed models of proteins can be an effective educational tool [17]. It is like a sculptor who molds from clay. They do not merely see the form. They feel it. With their fingers. With their palms. With their whole body. And when they mold, they do not think about a formula. They think about the form. Which is born under their hands. So it is in biology. A student who merely looks at a diagram does not understand biology. A student who touches a model, assembles it, and feels how the organism works understands. Because they do not merely see. They feel. And this sensation remains with them. Forever. As the ability to swim remains. Or to ride a bicycle. Or to speak. Because it is not in memory. It is in you. In your hands. In your body. In your life. And this is the most important thing. Not the diagram. But the sensation. Which makes you a researcher. And not an executor. And this is precisely education. Not the sum of knowledge. But the sum of sensations. That you have experienced. And which have made you who you are. And who you will become. In the next investigation. In the next sensation. In the next life.

An Experiment That Begins with a Question

Now I will turn to the concrete. What does a biology lesson built on the principle of dual purpose look like? I propose several examples - from simple to complex. The traditional approach: the teacher explains photosynthesis, and students memorize the equation. The approach that develops thinking: students first predict, then observe, then explain. Topic: photosynthesis and gas exchange in plants. The teacher gives the task. Prediction: if I place a sprig of elodea in water with carbon dioxide and put it in the light, what will happen? Will bubbles be released? What gas is it? Write down your prediction and justify it. Observation: students conduct the experiment or watch a video. They observe the release of bubbles in the light and their cessation in the dark. Explanation: why are bubbles released only in the light? What gas is released? How is this connected with photosynthesis? Write the reaction equation. Research shows that the POE intervention influences relational conceptual changes and scientific inquiry abilities in students [18]. What mental mechanisms are developed? Forecasting - through predicting the result. Causal relations - through explanation. Critical thinking - through comparing prediction and observation [1]. It is like a child who plants a seed. They do not merely put it in the ground. They wait. They observe. They water it. And when the sprout appears, they are surprised. Because they did not know that it would be like this. They supposed. But did not know. And this surprise - it is the beginning of biology. Not a formula. But surprise. Which makes you a researcher. And not an executor. And this is the most important thing. Not the result. But the process. Which changes you. Makes you different. More attentive. More patient. More thoughtful. And this is precisely education. Not the sum of knowledge. But the sum of changes. That have happened to you. While you were waiting. While you were observing. While you were living. And biology is one of the most powerful instruments for this. Because it does not forgive mistakes. But it also teaches one to find them. And to correct them. And to move on. To a new experiment. To a new discovery. To a new life. Which always begins with the first step. That you make. Now. Here. In this experiment. In this life. In this world. Which awaits your step. And your thought. And your decision. Which will change everything. Or change nothing. But you will make it anyway. Because you are a biologist. And a biologist cannot not think. Just as they cannot not see. Just as they cannot not live. And this is the most important thing. Not the formula. But life. Which makes you who you are. And who you will become. In the next step. In the next thought. In the next life.

Walls in Which Life Lives

The development of mental mechanisms requires not only new methods of teaching but also an appropriate infrastructure. For biology this means creating spaces where biological thinking can develop through practical, research, and creative activity. By creating this infrastructure, we form what Andy Clark and Kim Sterelny call a cognitive niche. Infrastructure is not merely premises but the material part of the environment that provides scaffolding for the development of mental mechanisms. Without this niche the mechanisms remain abstract concepts. A biology laboratory: a space for microscopy, growing cultures, and conducting experiments. Research shows the importance of experimental activity for the development of scientific skills [8]. A greenhouse or conservatory: a space for studying plants, ecological interactions, and botany. The Miami, My Garden program shows the effectiveness of school partnerships with botanical gardens [20]. An ecological trail or school plot: a space for observations in nature, studying ecosystems, and collecting data. A living laboratory where systems thinking develops through direct contact with nature. A virtual laboratory: a space with computers for modeling ecosystems,

working with genomic data, and using visualization programs. Research shows that the development of STEM-based learning materials can effectively promote higher-order thinking in biology education [10].

The creation of this infrastructure is not an expense but a strategic investment. Every child who, through these spaces, finds their entry point - whether it be experimental biology, ecological projects, or work in the greenhouse - receives a powerful impulse for the development of all the other mental mechanisms [1]. It is like a city. In the city there are libraries, theaters, and workshops. And every child can find what is closer to them. And having found it, can grow. Not because they are forced to. But because the environment allows it. And this is the most important thing. An environment that allows. And not an environment that demands. Because one can demand much. But to allow is an art. And the school must be an art. And not a factory.

Roots and Branches

Biology does not exist in isolation. It is connected with all the other subjects - and these connections can be used for the development of mental mechanisms. Biology and chemistry: biochemistry and molecular biology - the understanding of the chemical foundations of life [6]. Biology and physics: biophysics and physiology - the understanding of the physical principles of the functioning of organisms [6]. Biology and geography: ecology and biogeography - the understanding of the distribution of life on Earth [1]. Biology and computer science: bioinformatics and modeling - the use of computational methods for understanding life [10]. Biology and psychology as a new subject: neuroscience and the physiology of behavior - the understanding of the biological foundations of the psyche [7].

The Science of Life and Complexity

I want to end this article with what is perhaps the most important thing. Biology is not merely a school subject. It is the science of life, of the most complex systems in the Universe. It teaches us to see how a complex whole arises from simple elements, how systems evolve, adapt, and self-organize. It forms the cognitive apparatus capable of systemic, multiscale, evolutionary thinking. This is precisely why biology, in my view, is the key subject for the formation of the communicative-cognitive framework of personality [1]. When we teach a child biology, we teach them not merely to memorize terms and classifications. We teach them to understand life - how it is structured, how it develops, and how we ourselves are part of it. We teach them to think systemically - to see connections, to understand emergence, and to forecast consequences. We teach them to understand complexity - not to fear it but to see beauty and order in it.

This is precisely why the restructuring of the teaching of biology is not merely a methodological question. It is a strategic task. As I showed in the article on epistemological recursion [7], contemporary neuroscience is stuck in the trap of correlations: we record the results of the brain’s work but do not understand the mechanism of its self-organization. The brain is a complex system in which consciousness arises from billions of neural interactions. Understanding how this happens requires precisely the type of thinking that biology develops - systemic, evolutionary thinking that understands emergence. And if we want our children to become not merely knowers of terms but understanders of life, we must give them this instrument in full. Not for grades. Not for examinations. For the sake of understanding life. For the sake of life. For the sake of being able to see the world not as a set of separate facts but as a system of connections. And so that they can not merely live in this world but understand it. And, perhaps, change it. For the better. With the help of biology. Which does not merely classify. It understands. Like Darwin, who saw history in the tree of life. Like Ukhtomsky, who saw in the dominant the principle of the organization of life. Like a biologist who sees the truth where there is still only a cell. And this is the most important thing. Not the cell. But the truth. Which stands behind it. And which can be seen. If one learns to look. And if one knows where to look. And biology teaches this. Every day. In every lesson. With every child. With every experiment. Which is not merely conducted. It is thought through. And in this lies its strength. And in this lies its beauty. And in this lies its meaning. Which does not end. As biology does not end. As thought does not end. As life does not end. And this is the most important thing. The most valuable. The most genuine. And the most human. That we have. And that we can pass on. To the children. To the future. To life. Which continues. In every cell. In every ecosystem. In every discovery. That we create. And that remains. When we leave. Because discoveries remain. Laws remain. Thoughts remain. And biology continues. Even when we are silent. Because silence is also part of biology. And sometimes the most important part. The deepest. The most human. And this too is biology. Which does not end. Which continues. In us. And in them. And in those who will come after. And will read. And will understand. And will write their own. And

this will be a continuation. Not of an end. But of a beginning. The beginning of a new conversation. A new dialogue. A new understanding. Which does not end. As biology does not end. As life does not end. As thought does not end. Which seeks. And finds. And seeks again. Because in this lies the meaning. Not in answers. But in questions. Not in full stops. But in ellipses. Not in the end. But in the continuation. Which is always possible. As long as there is a cell. As long as there is life. As long as there is thought. As long as there is life.

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