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Learning Self-Reliance and Initiative of High School Students in Educational Modeling

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The task of the work is to present initiative and independent educational modeling as the highest possible achievement of high school students (15—17 years old). The application of the "case study" within the framework of a multi-year genetic-modeling experiment made it possible to describe the precedents of educational modeling in high school, demonstrating the initiative and independence of students in modeling. An analysis was carried out of video recordings of 14 lessons on setting and solving one educational problem, the results of a focus group with 5 teachers and written work of 20 eleventh grade students. Due to prior learning based on the principles of learning activities, students of this age are able to invent and analyze modeling tools necessary to capture implicit subject relations, as well as to transform the model by holding the problem for the time necessary to solve it. In this case, the training model acquires the features of an exploratory model. It is shown that the model is not only a means of fixing subject relations for the classroom community, but also a way of expressing their understanding, i.e. a means of communication.

Keywords: learning modeling; high school students; learning task; learning try-out learning initiative; learning self-reliance.

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Самостоятельность и инициативность старших школьников в учебном моделировании

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Задачей работы является представление инициативного и самостоятельного учебного моделирования как высшего возможного достижения учеников старшей школы (15—17 лет). Применение «case study» в рамках многолетнего генетико-моделирующего эксперимента позволило описать прецеденты учебного моделирования в старшей школе, демонстрирующие инициативность и самостоятельность учеников в моделировании. Был осуществлен анализ видеозаписей 14 уроков постановки и решения одной учебной задачи, результатов фокус-группы с 5 учителями и письменных работ 20 учеников одиннадцатого класса. Показано, что при условии предшествующего обучения, основанного на принципах учебной деятельности, ученики этого возраста способны самостоятельно изобретать и анализировать модельные средства, необходимые для фиксации неявных предметных отношений, а также преобразовывать модель, удерживая задачу в течение времени, необходимого для ее решения. Учебная модель при этом приобретает черты исследовательской. Она является для учебного сообщества не только средством фиксации предметных отношений, но и способом выражения своего понимания, то есть средством коммуникации.

Ключевые слова: учебное моделирование; старшие школьники; учебная задача; учебная проба; учебная инициатива; учебная самостоятельность.

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Introduction

One of the founders of the theory of learning activity, V.V.Davydov, identified the problems of the subject of learning activity, the connection between the formation of learning activity and the development of the personality of a student, as well as the problem of the development of learning activity itself as the most important unresolved problems of the theory [2]. In the almost three decades since then, these issues have been subjected to theoretical and experimental development ([see, for example, [6; 7; 8; 10; 11; 13; 16]), but are still far from final solutions. This is partly due to the fact that the main research method in this area is the genetic-modeling method, which determines the necessity of preliminary long-term design and implementation of educational courses based on logical-subject and logical-psychological analysis. The development and testing of such courses for middle school in 2000—2023 made it possible to discover and describe some phenomena which characterise changes in the nature of learning activity of adolescents compared to that of younger students, and to build hypotheses regarding the dynamics of learning activity and the development of its subject [11].

According to B.D. Elkonin, the key issue of the theory of developmental learning today is the question of mastering and dynamics of modeling: how it is tested in collaborative activities in elementary school; how the model becomes its own tool; how and when the model is transformed by students themselves [10]. This is not accidental, since modeling is the center and “soul” of learning activity. Changes in the nature of involvement of students in educational modeling should most vividly demonstrate the dynamics of learning activity and its subject in the course of age development.

The task of this article is to describe the precedents of educational modeling at biology lessons in middle and high school. The material of the research is the study of microevolution as a key and difficult task of teaching biology [3; 13; 15]. The ultimate goal is to present initiative and independent educational modeling as the highest possible achievement of the age, i.e., according to D.B. Elkonin, the norm of age development [12].

Methods

The main method used for data collection is a formative experiment within the framework of biology course, which allows us to observe the setting and solution of a learning task on the discovery of the concept of natural selection (Moscow gymnasium, 8-10 grades in different years, 8—11th grades of biology specialized classes). We have presented a description of this genetic-modeling experiment in earlier papers [3; 11; 13; 25]. The experiment involved a case study, traditionally used to study such precedents in teaching [15; 18; 20]. It relied on the included observation and analysis of video recordings of 14 lessons in 4 classes (three 9th grades and 11th grade, 108 students in total), which provided an opportunity to capture the events of collaborative learning activity. The video recordings were used to assess the measure of the autonomy of the students’ work (recording the main stages of their work, moments and nature of the involvement of the teacher in independent work of the class).

In order to clarify and test the hypotheses, there was formed a focus group with 5 teachers working in different classes (all worked with experimental classes during last 4—10 years). The task in the focus group was to record the subjective perceptions of teachers about the autonomy of students in the process of modeling and their readiness to provide students with this opportunity, as well as to describe a variety of initiatives of children in modeling microevolution during ten years of experimental work.

The analysis of the written work of 20 eleventh grade students (9 boys, 11 girls) made it possible to analyze their involvement in collaborative learning activity, as well as their perceptions of the process and results of collaborative educational modeling.

Results

For the first few years of the development and implementation of the New Biology course, the learning task of discovering natural selection was reproduced according to a single scheme in different schools and grades (from 8 to 11). This significantly increased the efficiency of learning compared to traditional learning [3; 9; 13]. Mastering the specific skills which are required to organize the setting and solving of a learning task in the classroom made it possible for teachers to make their own trials. The trials consisted in giving more freedom to students in setting a learning task and creating an educational model.

The "traditional" way of working in this part of the course has been described in detail [3; 9], but it is necessary to highlight the essential stages of this movement so that the changes and their consequences, tested by teachers later, become clear.

1. Students discover a contradiction in their own explanations of evolutionary change: mutations are random, while evolutionary change appears to be purposeful.

2. Emergence of the idea of developing an evolving model object.

3. Development of the model object: forms of its "existence", rules of its "life" (about 1—2 lessons) — paper squares of two colors, on the back side of which their genotype is written down, laid out on a certain background.

4. Game modeling. Discovering the fact of population dynamics depending on environmental factors (approximately 2 lessons).

5. Analyzing the results obtained. Distinguishing between guiding and non-guiding factors, discovering the fact of natural selection (approximately 2 lessons).

6. Familiarization with the theory of C. Darwin and the term "natural selection".

7. Solving problems for final comprehension of the discovered regularities.

The educational model was developed by a community of methodologists, teachers and psychologists. The teacher, presenting in advance the final format of the educational model, organized the activity of students who were discovering these subject relations for the first time.

Unlike most teaching strategies, in the system of D.B. Elkonin—V.V. Davydov, students are almost never offered a ready-made educational model. Educational modeling is the fixation by students of essential subject relations in a sign-symbolic form and the subsequent transformation of this sign-symbolic form: each class always reinvents this "wheel".

Working out the rules of the "game" (creation of an educational model) is more important than the actual game modeling of microevolution[1]. By proposing rules, students demonstrate their understanding of biological phenomena, elaborate it in the discussion, and, already at this stage, compare the created model and reality, repeatedly making such transitions. However, the teacher's precise questions and remarks lead to the development of very clear rules. For example:

T (teacher): How many traits shall we take?

S (students): Let's take 5! Let's take 2!

T: It is probably best to choose the easiest option for research.

S: Then let's take one, because Mendel did that at first.

Up to 6th or 7th grade, students do not notice or easily forgive such interference by the teacher, wondering how it happened that they were searching on their own, not knowing what they would find, while the

[1] A considerable number of ready-made computer models of evolution are known, including those in Moscow Electronic School and Russian Electronic School. The use of ready-made models of evolution to demonstrate regularities to students somewhat increases the efficiency of learning [14]. But ready-made models cannot replace independent development and implementation of a educational model: the mechanism "stitched" into a ready-made computer program is hidden and makes the results of this program indistinguishable from magic for the user and, therefore, unconvincing. In addition, dice and coin tosses allow students to feel "with their own skin" the probabilistic nature of evolutionary factors.

teacher guessed in advance what would happen.

In high school, some students feel the artificiality of the situation: it seems that they are given independence in developing the rules, but it turns out that the teacher has prepared all the materials (a box with cut papers of two colors, etc.). Perhaps that is why some students started to behave more passively, not offering additional ideas. In the process of the game, these students did not try to ensure the accuracy of following the rules: if the model is ready in advance, the results are already known.

The teacher, according to the teachers who participated in the focus group, could suffer from the role of "imposer", but did not deviate from the developed logic due to the fear of "moving in the wrong direction", "wasting time", etc. The risk in departing from the established model is also that the changed model may not explicitly show the regularities that the students are supposed to discover. Therefore, the teacher must be quick to think several steps ahead when making changes. It is important to understand the effect that a modeling rule introduced by the students will have on the model.

After several runs of this fragment of the course in different classes, teachers began to feel more confident in their abilities and understanding of the situation, which led to trial actions on their part. This was manifested in accepting the options proposed by the students, if they were sensible to such an extent that it was incorrect to impose one's own, premeditated option, as it was no better than the one proposed by the children. For example, in one class, students did not want to introduce into the model a "predator" that destroys lighter colored specimens because they are better seen against the background. A student said that this was "childish" and suggested introducing the factor of ultraviolet radiation, since the dark-colored papers would be better protected from it than the lighter-colored ones. The teacher did not block this suggestion because they realized that it was quite consistent with reality and such a change would not ruin the model. Moreover, it turned out that now the "survival" of the papers no longer depended on the will and consciousness of the "predator", but was determined by the roll of a die.

In many classes, students on their own initiative wrote programs for processing the obtained data, programs that accelerated the most time-consuming and lengthy stages of paper modeling. Frequent attempts to switch from "manual" modeling to virtual modeling — creation of computer programs simulating evolution — were noted.

Attempts of students to not choose paper as a model object, as well as to choose not only color as a phenotypic trait, were still suppressed by teachers: it seemed to them "very difficult to think of another working model and not to get confused".

Over the years, teachers began to allow for more extensive changes. For example, in one biology class, a different way of assigning selectivity was proposed: specimens in a simulated population were designed to be sensitive or insensitive to an antibiotic. To determine which of them would survive and which would die, children threw a handful of grains from a bag onto a table with papers representing living creatures. If a grain landed on a piece of paper, it "survived" if it was resistant according to its genotype and "did not survive" if it was not resistant.

Trials of the teachers were supported by the increased confidence that even with considerable variation the model remained operational, as well as by the fact that the teachers noticed the effect of giving students the freedom to formulate the rules of modeling. The involvement of students was higher.

This led teachers to identify the fundamental points in modeling which needed to be controlled (there are only four) as opposed to those which could be varied.

The most recent episode of setting and solving this educational task (biology specialized eleventh grade, academic year 2022-2023) fully demonstrated the potential of the class as a learning community in relation to modeling. The teacher took the risk of allowing the children almost complete freedom in setting and solving the problem. This was possible because of his confidence in the skills of the students and the sufficient time he was able to allocate to the task.

Good preparation of students was expressed in successful mastering of the previous material and familiarity with the next topic, Evolution. However, as in other similar cases, the knowledge preceding the new topic was formal. Children were surprisingly successful compared to previous classes in solving the task about a giraffe which preceded the setting of the educational task, probably because this material is often found in textbooks and other books about evolution. However, a similar task on bacteria showed lack of understanding of the mechanism of microevolution. This corresponds to our ideas about the necessity of modeling to fully master the concept.

The setting of the educational task and the choice of the way to solve it took place during the discussion of the results of the previous work. Here is a shortened dialogue between the teacher (T) and the students (S):

T: What did you get?

S: Evolution is happening. Modifications are not inherited and mutations are not directed.

T: Can mutations be the basis of evolution?

S: It is not clear.

T: How do you find out? What are some ways to prove or disprove in science in general?

S: Read books and articles on the subject. Do an experiment. We would like to do it ourselves.

T: A real experiment is impossible in our conditions.

S: We can also do some modeling. On a computer.

T: I guess you can do it without a computer too... So what should we do: read textbooks or do modeling?

The students then went straight into developing rules for modeling.

The first suggestion was to take a word that can mutate (for example, vowels can be replaced by consonants) as a “living creature”. However, the elaboration of this version showed that it was difficult to fulfill, and the students began to think of another alternative: with plasticine balls and “sausages”. The whole work on developing the rules, testing them and changing them lasted five lessons, during which the students were active and independent. The teacher intervened in the process only a few times, namely:

1. Sometimes asking if this happens in nature.

2. Initiating an analysis of the situation when they noticed that the process was taking too long and becoming boring — the students had originally set a very low rate of reproduction in the model.

3. Holding on to the idea that the students had not included the non-guiding factors of evolution in the model from the beginning, suggesting to add a cold winter at the stage of re-analyzing the rules of the game.

4. Pointing out the insufficiently marked difference between flat “sausages” and balls made of plasticine: if you act with your hands, you may not feel the difference.

5. Suggesting to strengthen the action of one of the acting factors chosen by the students in a situation where it was found that they act in opposite directions with equal force.

6. Organizing the simultaneous creation of an Excel file to process the data for all groups.

After the simulation, the students were asked to write a report on how they acted: “Describe what was memorable, what was interesting”. The task was not compulsory. Of the 20 students who took part in the modeling, more than a half wrote reports. As the task was vaguely formulated, the reports varied: short and long (up to three pages), concise and full, less and more reflective. The results of this work are presented in Table.

In 10 reports, students used the word “we” when describing the modeling process, for example: “We decided to model the process of evolution...”, “We divided the specimens into groups of 5 bibcas[2], with genotypes AA and aa (balls and sausages)...”, “We began our model of evolution with the idea of text....”, “Our hypothesis did not fit, because we did not know how to make mutations...”, etc. One report was entirely devoted to analyzing the model and one’s attitude to it. Another paper did not use the word “we” because the whole description was a detailed analysis of the interaction between groups (“some people believed”) and individual students, mentioned by name.

The majority (see the Table) understood the modeling process as a work of thought with hypothesis generation, testing and correction. Students recorded mainly significant moments in the development of the model, pointed out the turns of collaborative thinking, e.g.: “...according to the results of round 1, three out of four groups did not show a significant increase in the population, so it was decided, that there will be better to use schizogony instead of non binary division ...”, or “The predator ate with closed eyes tactilely. Since the meet balls stood out more, it ate them more often than the sausages. The results were not very realistic and we decided to add more conditions”.

The overwhelming majority had their own point of view on the course and results

Table

Analysis of the students’ reports on the progress and results of the modeling

Characteristics of collective educational modeling highlighted in students’ works	**Number of students who highlighted these characteristics (out of 12)**	**Number of mentions in one report**
Problem setting and choosing the solution method	2	1—2
Description of an unsuccessful modeling attempt	4	3—4
Recording of the **essential** points of the modeling (frequency of mutations included in the model, their probabilistic nature...)	10	4—10
Recording of **non-essential** (external) moments of modeling, e.g. a name invented for “living beings”	8	1—3
Recording of turns of thought (rejection of ideas)	8	1—5
Evaluative and reflective judgments about the process and results of modeling	10	1—8
Pointing to one’s actions or role in this work	4	1
Pointing to the role or actions of another student	3	1—4
Pointing to the actions or role of different groups	8	1—3
Pointing to the actions or role of the teacher	2	1—2

[2] “Bibcas” was the name students gave to the specimens of the population the evolution of which they modeled (the name of the fictitious animals). Children's work is cited without change.

of the modeling, expressing evaluative and reflexive feedback on the course, intermediate and final results of the modeling, and on the peculiarities of the model being created, for example: "It seems to me that the facts are too balanced and monotonous (obviously, they mean factors — *author's note*). I think we could add some single intervention like an epidemic or other cataclysm.", "...now and in the lesson, it is not clear at all what conclusions can be drawn from the model in theory. But it made the term gene pool very clear", "First of all, I remember Anya's first model well, because at that time I was thinking about some model myself, and Anya's idea seemed very reasonable, unusual and very interesting", "We have a strangely selective predator, however, it is not immediately clear how it works, how exactly it influences evolution — we have not formulated it correctly", etc.

While detailed descriptions of their own actions in the first person plural or singular were present in all the works, brief indications of the teacher's involvement were found only in two works.

An interesting fact revealing the students' engagement in the process is that one of the modeling participants left the New Year disco to go to the biology classroom, where the teacher found him writing formulas on the blackboard. The student wanted to look at cases of combinations of variables in their model. Later, the teacher gave him the opportunity to share this with the class.

Solving a learning task and discovering the mechanism of microevolution does not imply full mastery of the concept. It is necessary to solve tasks in which the concept is specified and clarified, as well as to perform learning trials — solving tasks of a special type in which there is no requirement or hint to apply the concept.

It is interesting that in this case, in the very process of solving the learning task, the students made this learning trial in relation to an earlier model they had built — they proactively used a model/concept introduced in the biology course four years earlier. This is the concept of the relation of the surface area and volume of a body to heat absorption. The "living things", which were invented by the students and the populations of which had evolved, differed precisely on the basis of the body surface area at constant volume (flat "sausages" and balls) and that is why they "survived" differently in cold winters and hot summers. This shows the expansion of the functional field of this model/comprehension [4] and its mastering by most of the students in the class.

The comprehension of the concept of natural selection and other factors of micro-evolution occurred by analyzing real examples, in each of which students discovered the action of different factors: driving selection on the example of wingless island insects, migration of beetles of Lake Erie, etc. In the work of comprehension and specification of the discovered concept, we saw no significant differences from the traditional course of this work in the New Biology course. The process was neither faster nor simpler.

However, the question "What is Darwin's main merit?", which was posed to students after the modeling but BEFORE the class had studied Darwin's theory, made this class stand out from the others. Most answers to a similar question in other classes identified Darwin's main merit as "proving the ancestry of man from monkeys". In this class, most students wrote that Darwin discovered "the true mechanism of evolution" and "created a correct theory of evolution". Four papers out of twenty said, "Darwin proved that evolution is based on mutations", which is certainly incorrect (in Darwin's time, mutations were not yet known), but demonstrates that modeling "triggered" a process of rethinking earlier ideas.

Due to the independence and involvement of students in modeling, the concept of natural selection acquired a strong personal meaning for students. This was discovered while watching a film shown on the Culture channel dedicated to Darwin's jubilee. Without commenting on the film in advance, the teacher asked students to describe their impressions. Most of the works gave a detailed, critical and emotional analysis of the film, which revealed its true intention and was based on the analysis of facts and their contradictions. The following are some quotations from the students' works:

- "... I saw two valid facts that "disprove" Darwin's theory (and the film, made for the anniversary of his birth date, was most likely made for this purpose). The first is that ancestors were found together with already existing species. I really want to ask the authors of the film: does their so eagerly defended grandmother exist if she lives at the same time with them? The second is that the Darwinists themselves do not believe it, and all the evidence is falsification. I was sincerely waiting for an explanation of the falsifications, but there was none".
- "….. it was not the monkey theory, but the theory of natural selection that "turned the idea of the world creation upside down"; this is the major Darwin's point..."
- "Darwin in his theory only talked about the creation of new species from old ones, not the creation of old ones (or rather, the old one)... It is good that young people do not watch TV nowadays..."
- "The law of embryonic similarity has been shamelessly reformulated..."
- "There are no questions about the video, music and the narrator, but there are questions to the author of the text, because there were factual and conceptual errors..."

One student expressed his criticism of the position of the authors of the film in a poem:

"We don't need steps to be our guide.
No need for a forest's abode.
Perhaps a meteorite, or comet bright,
But not natural selection's code".

Discussion

During the first years of elementary school education according to the system of D.B. Elkonin—V.V. Davydov, children's skills of educational modeling gradually take shape and grow. In the process of collaborative work, students begin to actively use sign-symbolic means proposed by the teacher to depict invisible object relations, and then actively suggest their own ways of schematic fixation [1; 8] and transform the model, acting as a whole class and then independently.

New subjects are introduced in middle school. The specificity of subject concepts makes developers look for specific forms of educational models, which only partially reproduce the features of research models of the corresponding field of science. Therefore, students get involved in educational modeling as if anew, mastering new modeling languages. For many fifth-graders, involvement in modeling, indeed, occurs for the first time due to the fact that the majority of schools in which the D.B. Elkonin—V.V. Davydov system continues to be practiced only work with this system in elementary, or, on the contrary, only in middle school, many students at this stage go from one school to another. We do not have comparative data on whether involving children in educational modeling is easier or more difficult at this stage compared to elementary school. However, in the conditions of education according to the D.B. Elkonin—V.V. Davydov system, in middle school even a newly recruited class quickly begins to behave as a learning community, solving learning tasks together.

In middle school, the very nature of modeling changes [11], the complexity of educational models increases, sometimes to such an extent that it becomes difficult, and sometimes impossible, for the teacher to keep and anticipate the possibilities of changing models in the course of discussion and collaborative development. The microevolution model discussed in this article approaches exploratory science models in complexity and nature. For example, the students' proactive introduction of two selective factors acting in opposite directions led to the manifestation not of classical driving selection but of selection on balanced polymorphism. Participating in the creation of a completely new model, the teacher cannot operate "in autopilot". His/her interest and position not as an expert but as a helper, an almost equal participant in the development, strengthen the students' involvement in solving the problem.

The analysis of children's reports shows that the class in the situation of solving a learning task behaves and feels like a learning community, acting together, consciously and purposefully. Pupils are able to conduct a discussion without the teacher's help, keep a goal indefinitely, break into groups and coordinate collaborative work. Students do not give much importance to the teacher's work in this situation, accepting him or her as one of the knowledgeable and appropriate equal members of the community. This is evidenced by the low number of mentions of the teacher's interference in the process in the children's reports.

When creating an educational model, students act in a subject-specific manner, relying on the key subject concepts they have previously mastered, independently and proactively propose meaningful hypotheses, identifying subject relations that can be the basis of the model. They consciously select a model form and analyze its suitability to model specific relations, rejecting unsuitable variants. Students' reflexive attitude to the modeling process manifests itself in critical remarks during the process, in insightful assessments of its intermediate and final results.

The intervention of the teacher in this process is necessary only if the students do not independently retain the essential facts that the model should reflect. In the last case described, such intervention was required once (introduction of a non-selective factor[3]). Sometimes the teacher makes an organizational intervention, such as coordinating work of the group, because he or she sees the whole class without participating in group work. In this case, this was also the only intervention.

Thus, it can be recorded that at the high school stage, the model becomes a means of students' own research action, which confirms earlier hypotheses [1]. High school students invent model means themselves, which allows them to demonstrate their own understanding and ensure interaction in the learning community.

Needless to say, the process of independent educational modeling takes 2—3 times more class time than teacher-directed work, primarily because there are more dead-end moves to be played and rejected than in a tightly controlled situation. However, the result of independent modeling is not only a completed educational model, but also the very experience of such modeling [5]. The question of whether it is more important to spend learning time on students gaining experience in proactive independent research or on familiarizing them with an abundance of specific knowledge remains a question about the values of education.

Conclusions

1. Educational modeling in high school can be an independent and proactive ac-

[3] It is important that this point is not necessary for the discovery of natural selection, but is important for a broader and more accurate understanding of microevolution.

tion of the class learning community, provided that there have been previous years of studying in the form of learning activity and that the class at this age stage is given the opportunity to be a proper subject of its learning activity.

2. The educational model created by the class acquires the features of a research model.

3. When developing such model, students act on the basis of the key subject concepts/models they have previously mastered, they are able to invent new model means, analyze the suitability of sign-symbolic forms for modeling the subject relations under study.

4. The model independently created by the students becomes for them not only a means of fixing subject relations to obtain new knowledge about the studied object, but also a means of presenting their own understanding and a means of organizing subject communication with other participants of the learning and research community.

5. When conducting initiative educational modeling, students are able to independently keep the framework of the task, control the process of its solution, and coordinate the actions of the learning and research community, which can be considered the highest age-related achievement, i.e. the norm of age development.

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