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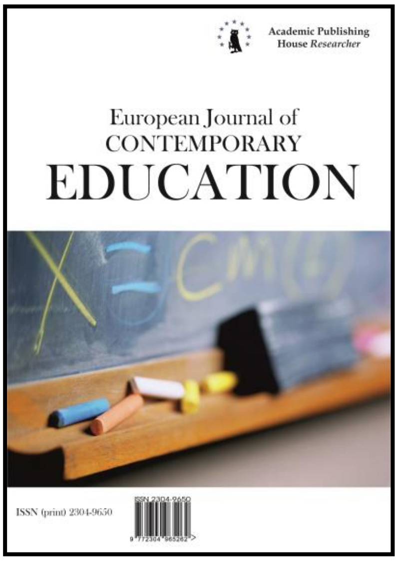

Assimilation and Forgetting of the Educational Information: Results of Imitating Modelling

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Abstract

Various approaches to the problem of computer modelling of assimilation and forgetting of the educational information are considered. With the help of the multi-component model the Ebbinghaus' curve of forgetting of poorly assimilating information to be remembered through recurrences is confirmed. It is taken into account, that while training there is a transition of weak (poor) knowledge into strong (firm) knowledge, and while forgetting – the return transition of strong knowledge into weak knowledge. Also the model of assimilation and forgetting of the educational material with a high links degree, consisting of information blocks which contain the connected concepts is created. It allows to explain that: 1) while training there is the sharp increase of the understanding level of the studied problem; 2) after termination (ending) of training during some time the level of the pupil's knowledge remains high, and then slowly lowers because of gradual forgetting of the separate learning material elements. The paper shows that the processes of assimilation and forgetting occur according to the logistic law. Along with that the imitating model of training at school which takes into account the knowledge division into three categories and distribution of the educational information on classes is offered. For all cases there are graphs of the knowledge level dependence on time.

Keywords: didactics, training, learning, forgetting, computer modelling, level of knowledge, information block, Ebbinghaus' law.

1. Introduction

The learning efficiency strongly depends on the pupil's perception, understanding, memorizing and forgetting of the reported information (Velichkovskij, 2006). The regularities of these processes are studied by experimental psychology (Zinchenko, 2002). The fundamental

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research in this area is the work by Ebbinghaus (1885), devoted to the study of laws of storing (memorizing) without participation of the thinking processes, in which the method of learning senseless syllables exciting no semantic associations was used. It is impossible to name knowledge received by the pupil at a lesson, as the senseless information; it is easily associated with concepts, laws and theories, which the schoolchild has got already. S.L. Rubinstein marks, that forgetting of the comprehended material is not described by the Ebbinghaus's curve (fig. 1.1); this process submits to different laws and happens considerably slower (Zinchenko, 2002, p. 136).

In our opinion, each information block and each pupil can be described by some latent parameter K_S which can be named as a linking degree. It characterizes the swiftness and lightness of the logic or associative links occurrence with knowledge, which the schoolchild already has. It is the knowledge linking degree, lesson duration and the teaching technique that the durability (strength) of the pupil's knowledge depends on. The purpose of the paper is creation and substantiation of the model of assimilation and forgetting of the learning material with a certain link coefficient, which includes: 1) the separate learning material elements (LMEs), untied with other concepts and remembered mechanically; 2) the logically and/or associatively connected information consisting of reasonings (ideas, theorem proofs, solving of the equations, etc.), which are acquired by means of their inclusion into the pupil's system of concepts. On the basis of the received results it is planned to create a model of training at school.

2. Research methods

The research uses the method of qualitative modelling, the mathematical and computer simulation methods. The qualitative model of the assimilation and forgetting is constructed and after this the transition to mathematical model which is system of the differential equations occurs. For the numerical solution of the differential equations the Euler's method is used. For modelling of assimilation and forgetting of the comprehended information the computer program recalculates a matrix of probabilities, increasing or reducing its elements, simulates "testing of the pupil" etc. The offered simulation models of assimilation and forgetting is based on the works by R. Atkinson, G. Bauer and E. Kroters (Atkinson et al., 1969), R. Bush and T. Mosteller (Bush, Mosteller, 1962), D. Gibson and P. Jakl (Gibson, Jakl, 2013), L.P. Leont'ev and O.G. Gohman (Leont'ev, Gohman, 1984), V.V. Mayer (Razumovskij, Mayer, 2004), F.S. Roberts (Roberts, 1976), A.P. Sviridov (Sviridov, 2009), Hunt E. (Hunt, 2007), and is the development of the approach stated in the works by R.V. Mayer (Mayer, 2014; Mayer, 2015; Mayer, 2016).

3. Discussion

The model should reflect the most important aspects of researched object, neglecting the minor ones. In case of modeling of didactic process the following purposes are usually pursued: 1) studying of an essence of that or other didactic object, process, component elements and links between them; 2) explanations of the known facts established by a method of the pedagogical observation and experiment; 3) forecasting of the didactic system behaviour in new conditions with various external influences and ways of management; 4) optimizations of functioning of the didactic system, search of the correct management according to the chosen criterion of an optimality. In dependence of the randomness degree of the simulated process we can distinguish: 1) the determined models, in which the random factors are not taken into account, and the changes of system state are depend only on its internal condition and external influence at the current moment of time; 2) stochastic models which work similarly to probabilistic automatic devices; their internal states and the reactions on an output at the following moment of time are set by a matrix of probabilities. The mathematical models are forming a wide class of abstract models, in which the logic conditions, algebraic or differential equations and random variables are used (Atkinson et al., 1969). To study the mathematical model, an analytical or numerical method (that is, with the computer help) is used. The computer (or imitating) models are an algorithm or computer program simulating the behaviour of the researched system "teacher – pupil" (Gibson, Jakl, 2013). Thus the methods of the numerical solving of the differential equations system, the automatic approach or multi-agent method are applied. Various aspects of the modeling problem of didactic systems are considered *in the book "Cybernetic pedagogics: Imitating modelling of training process" (Mayer, 2014), and also in articles (Mayer, 2015, Mayer, 2016).*

4. Multi-component model of training and the Ebbinghaus's curve

The model of learning of the poorly-associated information should correspond to the follows facts: 1) right after the end of short training the schoolchild's knowledge decreases quickly (fig. 1.1), then slower, and at $t \to \infty$ it remain constant (20-25 % from the studied material); 2) after long or repeated training the pupil firmly acquires the reported to him information; the forgetting speed is low.

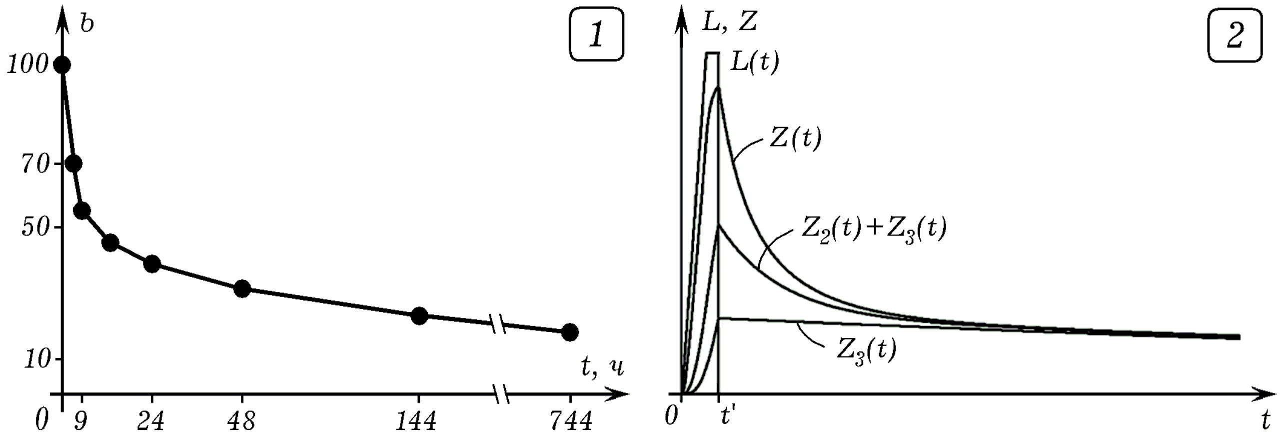

Fig. 1. The Ebbinghaus's curve (Zinchenko, 2002) and results of the simulation.

The described regularities of assimilation and forgetting is in agreement with three-component model of training, which is expressed by the system of four equations (while training $k = 1$, otherwise $k = 0$):

$$dZ_1/dt = k(\alpha(L - Z) - \alpha_1 Z_1) - \gamma_1 Z_1 + \gamma_2 Z_2,$$
$$dZ_2/dt = k(\alpha_1 Z_1 - \alpha_2 Z_2) - \gamma_2 Z_2 + \gamma_3 Z_2,$$
$$dZ_3/dt = k\alpha_2 Z_2 - \gamma_3 Z_3, \quad Z = Z_1 + Z_2 + Z_3,$$
$$\alpha = 0{,}1; \ \alpha_1 = \alpha_2 = 0{,}015; \ \gamma_1 = 0{,}027; \ \gamma_2 = 0{,}009; \ \gamma_3 = 9 \cdot 10^{-5}.$$

The model takes into account that: 1) the pupil's total knowledge Z is divided into the weak knowledge Z_1 (Kn–1), the average strength (or durability) knowledge Z_2 (Kn–2), the strong knowledge Z_3 (Kn–3) with forgetting coefficient $\gamma_1 > \gamma_2 > \gamma_3$; 2) the speed of the weak knowledge increase is equal $\alpha(L - Z)$, where L – the level of the teacher's requirements, Z – the total knowledge; 3) while training ($k = 1$) the weak knowledge partially turns into the strong knowledge; 4) with no training ($k = 0$) the strong knowledge partially becomes weak, and the weak knowledge is forgotten. For the solution of this system of equations the computer program containing the time cycle is used. It calculates and accumulates the increases of knowledge ΔZ_k ($k = 1, 2, 3$), corresponding to the given temporary step, and draws the graphs $Z_1(t)$, $Z_2(t)$ and $Z_3(t)$.

Let us take that during time t_1 the pupil tries to remember N learning material elements (LMEs) mechanically (for example, 30 foreign words) and uses the recurrence method. At first he tries to remember the first LME, then – the second LME, without forgetting the first LME, etc. At the end of training he should keep in memory all N LMEs. Thus the level of the schoolchild's requirements to his knowledge, grows with constant speed. Having once revised all LMEs within time t_1, during time $t_2 = t' - t_1$ the schoolchild repeats it again and again, trying to keep in memory all N LMEs. At this interval of time the level of the requirements L remains constant. Here training comes to an end ($t > t'$, $L = 0$), and forgetting begins. Fig. 1.2 shows the graphs which are the result of computer solution of the considered equations system. Under the given parameters of the model, about one fourth part of the studied information is remembered strongly and after the termination of training its quantity decreases very slowly. All other acquired knowledge is forgotten rather quickly. The graph $Z(t)$ on fig. 1.2 is very similar to the Ebbinghaus' curve (fig. 1.1).

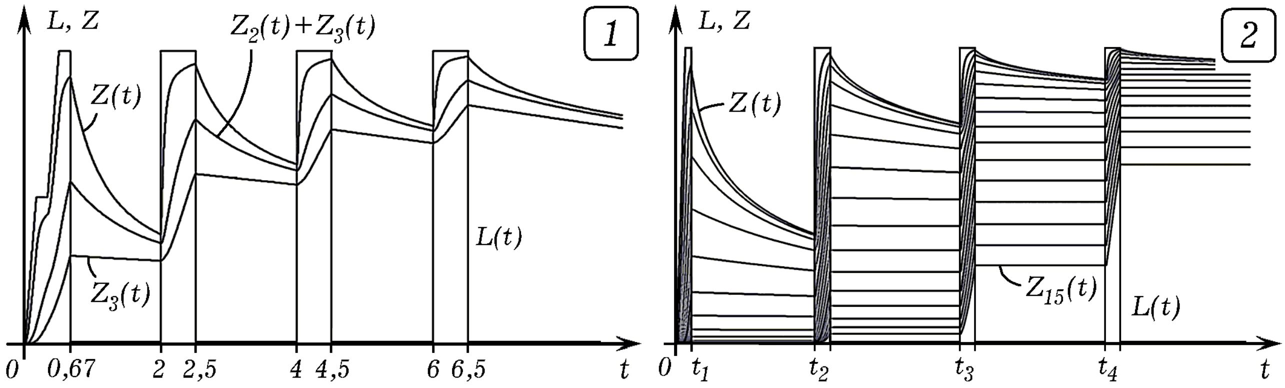

Fig. 2. The results of modelling: a) $N = 3$; b) $N = 15$.

Let us model the pupil, who studies some material within 40 minutes (0,67 hour), and then he repeats it several times. Let us take that on the first lesson he tries to remember the first half of some text, then he revises it, and then he tries to remember the second half of text and then he repeats the whole text. After that a break follows, and at the moment of time $t = 2$ hours the second lesson of 30 minutes (0,5 hours) begins, at which the schoolchild tries to learn the text again. The third and fourth lessons begin at the moment of 4 and 6 hours, their duration is 0,5 hours. The turning out curves which show the changes of the pupil's knowledge of various strength, are presented in the fig. 2.1. It is visible that after each lesson the quantity of knowledge Kn–1, Kn–2 and Kn–3 grows and in breaks between them – decreases. If the lesson duration increases, then the strength of the acquired knowledge grows.

Generalizing the considered above three-component model, we come to the following $N-$ component model of training (system of $N + 1$ equations):

$$dZ_1/dt = k(\alpha_0(L - Z) - \alpha Z_1) - \gamma_1 Z_1 + \gamma_2 Z_2,$$

$$dZ_i/dt = k\alpha(Z_{i-1} - Z_i) - \gamma_i Z_i + \gamma_{i+1} Z_{i+1}, \quad i = 2, 3, \dots, (N - 1),$$

$$dZ_N/dt = k\alpha Z_{N-1} - \gamma_N Z_N, \quad Z = Z_1 + Z_2 + \dots + Z_N,$$

$$\alpha_0 = 0{,}1; \ \alpha = 0{,}05; \ \gamma_1 = 0{,}03; \ \gamma_{i+1} = \frac{\gamma_i}{2{,}72}; \ i = 2, 3, \dots, N.$$

Here Z_1 – the quantity of the schoolchild's weakest knowledge, which are forgotten very quickly; Z_N – quantity of the strongest knowledge; αZ_1 – the transformation speed of the knowledge Kn–1 into the knowledge Kn–2. For the numerical solution of the equations system at $N = 15$ a special computer program is used. The results of modelling (fig. 2.2) correspond to real change of the pupil's knowledge rather well.

5. Constructing of a matrix model of the logically connected information learning

Now we consider a situation, in which the schoolchild acquires the logically connected information, for example, the conclusion of the formula, the proof of the theorem, a system of reasonings, etc. The mastering and forgetting of the logically connected educational material occurs according to the following regularities: 1) during training there is a fast qualitative growth of knowledge as a result of which the pupil suddenly begins understanding the material being studied; 2) often the pupil is not able to recall the specific learning material element (LME) directly, but he can recall it by association or logically deduce it from the LMEs known to him; 3) after the end of training if the pupil does not use the received knowledge, the reverse leap occurs: the comprehension level of the studied problem remains high at first, and then decreases.

While studying the logically connected material the pupil not only tries to remember a set of separate LMEs (concepts, formulas), he tries to acquire the sequence of reasonings. The important condition of fast and strong assimilation of the reported information is its understanding, that is inclusion of any new facts, ideas and theories into the system of knowledge and representations which the pupil has, making connections with the acquired information (Zinchenko, 2002). The essence of the offered approach is, that the educational material is considered as a set of N separate ideas or information blocks. Each block consists of M learning material elements (LMEs), ordered and connected with logic links. To understand any new idea the pupil should solve the given intellectual problem, that is to study a sequence of all LMEs, included into the given information block, in first time. When the schoolchild has acquired all LMEs of the given idea and, solving the educational task, again goes through their sequence, in second (fifth or tenth) time he turn to the concrete cognitive situation. This happens without active involvement of thinking and is called understanding-recollection.

Knowledge of the given (i,j)–LME is defined by probability $p_{i,j}$ of the correct answer to the corresponding elementary question (fig. 3). The probability of the specific idea reproduction by the pupil is equal to the product of the all LMEs reproduction probabilities making this idea. Each LME is connected to some LMEs from some other ideas (blocks). For the simplicity, it is possible to imagine a two-dimensional matrix of N lines and the M columns in which each element corresponds to probability $p_{i,j}$ of the corresponding LME remembering and is connected with nearby LMEs (fig. 3). The links degree is defined by coefficients $c_{i,j}$.

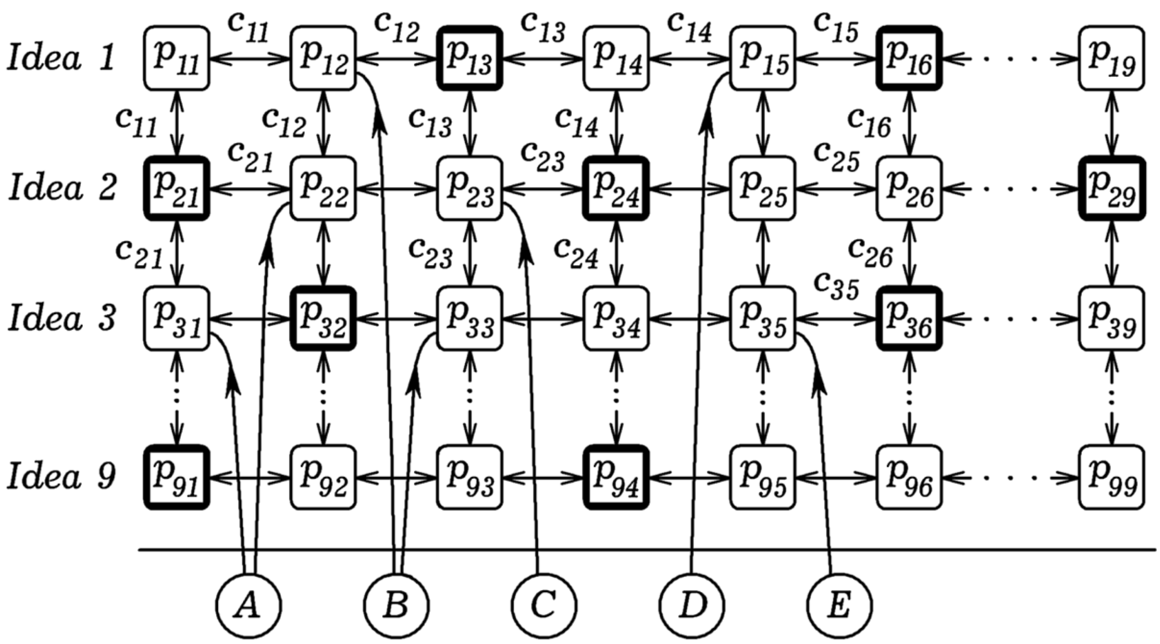

Fig. 3. The comprehended information as a system of N chains of the L LMEs.

We characterize the studied material by: 1) the amount of the ideas (LMEs chains); 2) the average length of ideas L; 3) the proportion D of LMEs known to the pupil a priori, that is before training; 4) the average coefficient of assimilation a. All LMEs can be divided into two categories: 1) well-known to the pupil; the probability of the correct answer for them is $p_{i,j} = 1$; 2) poorly-known to the pupil before the beginning of training, $p_{i,j} = 0 - 0{,}1$. Fig. 3 shows the first, second, third and ninth information blocks; LMEs of the first category (which are well-known to the pupil before training) are bold-framed. Each LME is connected with other LMEs (coefficient $c_{i,j}$ of some links can be equal to 0), and also with LMEs A, B, C, D, E which don't enter into structure of these logical reasoning chains. These links with external LMEs lead to increase in the assimilation coefficient $a_{i,j}$ of the given LME. We can take into account this fact, choosing $a_{i,j}$ from some interval in a random way.

Let us represent the poorly acquired LMEs ($p_{i,j} < 0{,}33$) in dark blue color, well acquired LMEs ($p_{i,j} > 0{,}67$) – in red, and all other LMEs – in green color (fig. 4). While training the average value p for all LMEs grows, blue sections turn into green, and green sections – into red. The more red and green sections in the line (information block), the higher the probability that the pupil has acquired this information block and will manage to do the corresponding sequence of reasonings. The more ideas the pupil has acquired, the bigger the probability of reproduction of all training material.

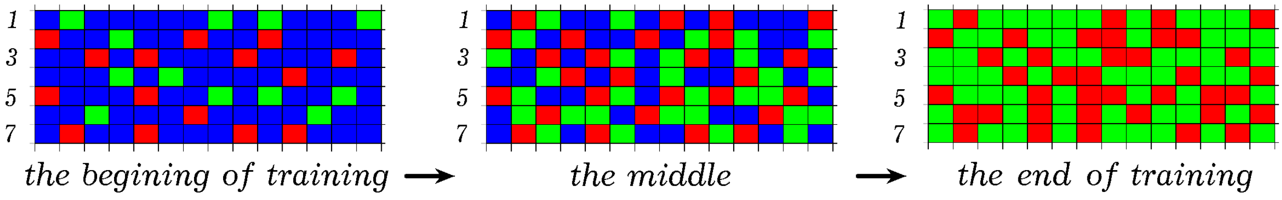

Fig. 4. Changes of the LMEs matrix while training.

It is important that the knowledge of one LME leads to easier assimilation and remembering of an other related LMEs. While training probabilities $p_{i,j}$ and the link coefficients $c_{i,j}$ increase: the pupil reproduces all sequence of reasonings (all information block) easily. To consider the fact that some LMEs are well-known to the pupil before training, the matrix $d_{i,j}$ is created where elements with the given probability D are equal to 1, and with probability $(1-D)$ – to zero. Let us take that while training the pupil carry out the sequence of the same educational tasks, consistently reproducing the idea after the idea, LME after another LME. It is known that while studying any logically connected material, the knowledge of one LME helps the pupil to study or recollect knowledge of another related LME. When studying j-th LME from the i-th idea within time Δt, the probability of the correct pupil's answer to the corresponding elementary question according to the law:

$$p_{ij}^{k+1} = p_{ij}^{k} + a\left(1-p_{ij}^{k}\right)\Delta t + c_{i,j}(p_{i-1,j}^{k} + p_{i+1,j}^{k} + p_{i,j-1}^{k} + p_{i,j+1}^{k})\Delta t.$$

Here $c_{i,j}$ is the coefficient of links allowing to note influence of other LMEs on assimilation of (i,j)–LME, k – the step number. For simplicity sake we consider all link coefficients identical and constant. The model considers that in the process of the knowledge level growing the pupil's operating time with (i,j)–LME decreases, aspiring to Δt. If at the given moment the pupil doesn't operate with (i,j)–LME, then owing to forgetting the knowledge of this LME within time Δt decreases according to the exponential law. The average value of probabilities $p_{i,j}$ for all LMEs in moment t is labeled as $p(t)$.

For an estimation of the pupil's knowledge and making the graph $Z(t)$ it is necessary to simulate the repeated periodic "testing" of the pupil at regular intervals. The pupil's knowledge of the i-th idea is determined as follows. The computer simulates the pupil's answer, in which he consecutively states the first LME, the second LME…, the L-th LME of the i-th chain (information block) during the given time.

The correct answer to the question corresponding the j-th LME from the i-th idea, is simulated as a casual process occurring to the probability $p_{i,j}$: the random variable x from the interval $[0,1]$ is generated and the condition $x < p_{ij}^{k} + c(p_{i-1,j}^{k} + p_{i+1,j}^{k} + p_{i,j-1}^{k} + p_{i,j+1}^{k})$ is checked. If the condition is true, it is considered, that the pupil has answered correctly, and if it is false – not correctly. In case of the wrong answer the pupil tries to reproduce the (i,j)-LME again, and in the case of the correct – he passes to the next LME from the same idea. If all L LMEs of the i-th chain are done correctly within the answering time $\tau = 1{,}3L\Delta t$, it is considered, that the schoolchild knows the i-th information block. The pupil's knowledge quantity $Z(t)$ is equal to the number of ideas (information blocks), which he can reproduce. At such "testing" the schoolchild's knowledge does not increase, the probabilities $p_{i,j}$ remain constant. For this modelling the program in Free Pascal is used.

Let us take that before training 10 % of all LMEs are known to the pupil, that is $D = 0{,}1$, their level of knowledge is $q = const$. The fig. 5 shows the results of modelling of assimilation and forgetting of the logically connected information in two cases: 1) there are no connections between LMEs (with $c = 0$, $a = 1{,}6$); 2) LMEs are connected with each other ($0 < c < 1$, $a = 0{,}4$). From results of modelling it follows: 1) even with no connections between LMEs the training leads to smooth increasing of $p_{i,j}$, that causes sharp rise of understanding $Z(t)$ educational material; 2) presence of connections with constant link coefficient c raises the probability of reproduction of the learned material by the pupil; the graph $p(t)$ bends in the other way, the advance $Z(t)$ is greater; 3) after the termination of training the average level of mastering of studied LMEs decreases according to an exponential law, but the knowledge level of the educational material at first practically does not decrease, then quickly reduces. If to take into account, that while training the connection coefficient $c_{i,j}$ grows, the transition from ignorance to knowledge is be sharper.

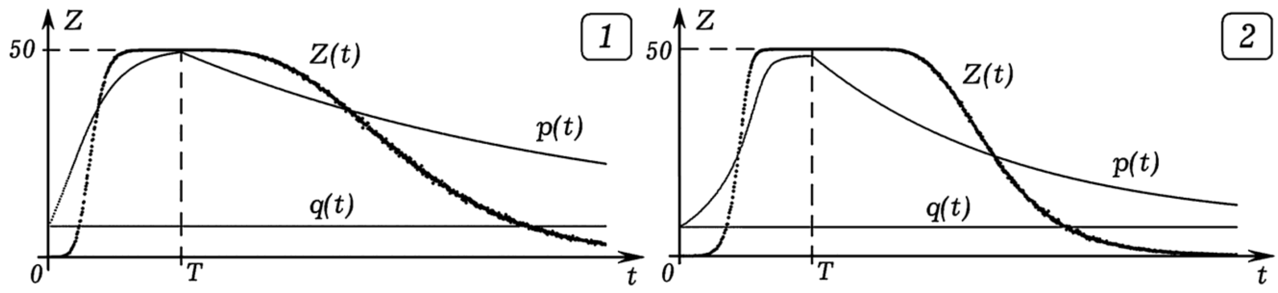

Fig. 5. The results of computer modelling of assimilation and forgetting.

The sharp rise of understanding is caused by the fact that the training material consists of the ideas (or information blocks), each of which contains the L number of LMEs. To reproduce the concrete idea, the pupil has to acquire all LMEs entering it; to acquire all training material he should learn to reproduce all ideas. Joint studying of LMEs, included in the given information block, leads to sharp increase in probability of its reproduction. Increase in the link degree between various LMEs promotes their easier storing (memorizing) and reproduction. Assimilation and forgetting of the logical connected information can be described by the logistic law: 1) assimilation: $dZ/dt = \alpha(I_0 - Z)Z$, where I_0 – the number of information blocks in educational material; 2) forgetting: $B = Z^0/100$, $x^0 = 100$, $dx/dt = -\gamma(100{,}5 - x)x$, $Z(t) = B \cdot x(t)$.

6. Computer modelling of school training

The proved regularities can be used for creation of the imitating model of training at 11-year school. The construction of model requires drawing up of system of the differential equations with their subsequent decision with help of the computer. The computer model will correspond to real process of training more precisely, if we take into account that strength and durability of acquiring of various topics are not the same. Therefore all LMEs should be divided into some categories, which the pupil forgets with different speeds. Let us select the following three categories: 1) the knowledge D used in the further activity and remembered very strongly; 2) the knowledge T of various theories, ideas, laws, reasonings, which are well associated with the concepts already known to the pupil, but not used in practice; 3) the abstract knowledge A of separate facts which are not used in further life and poorly associated with the concepts already known to the schoolchild. It is possible to assign the distribution of the educational information during all time of training at school (11 years) with help of three matrixes: 1) the quantity of the learning information in each class I_i =(30, 35, 40, 50, 65, 80, 100, 120, 145, 170, 175); 2) the share of the strong D-knowledge d_{1i} =(0,65; 0,6; 0,55; 0,5; 0,45; 0,4; 0,35; 0,3; 0,25; 0,2; 0,1); 3) the share of the weak A-knowledge d_{3i} = (0,05; 0,1; 0,1; 0,15; 0,2; 0,25; 0,25; 0,3; 0,3; 0,3; 0,3). Then the speed of the teacher's transfer and speed of the schoolchild's mastering of the knowledge of the first, second and third categories are equal: $v_{1i} = d_{1i}I/T$, $v_{2i} = (1 - d_{1i} - d_{3i})I/T$, $v_{3i} = d_{3i}I/T$.

When training the quantity of the pupil's knowledge for the corresponding class grows proportionally to the time: $Z(t) = Z_0 + v(t - t_0)$. Meanwhile all other knowledge decreases because of forgetting. The forgetting speeds of knowledge of the first and third categories are proportional to their quantity. The logically linked knowledge of the second category decreases according to the logistic law which has been mentioned above.

The offered mathematical model of training looks as follows:

$$\frac{dD_i}{dt} = kv_{1i} - (1-k)\gamma_1 D_i,$$

$$B = T_i^0/100, \quad x_i^0 = 100, \quad \frac{dx_i}{dt} = -\gamma_2(100{,}5 - x_i)x_i,$$

$$\frac{dT_i}{dt} = kv_{2i} + (1-k)Bx_i(t), \quad \frac{dA_i}{dt} = kv_{3i} - (1-k)\gamma_3 A_i.$$

When training in the j-th class the information acquired in 1, 2,..., $(j-1)$ classes is forgotten; therefore if $i = j$, then то $k = 1$, but otherwise – $k = 0$. To find the pupil's total knowledge $Z(t)$ in the given moment of time t it is necessary to summarize knowledge D_i, T_i and A_i in all classes ($i = 1,2, \ldots ,11$).

In imitating modelling there is a problem of a successful choice of the numerous parameters of the model. As it is marked by R. Shennon, many parameters of the computer model are frequently determined on the basis of the expert's assumptions who analyzes rather small amount of the data (Shannon, 1975). Along with this the behaviour of the model should correspond to a real situation greatly. In our case the parameters of the model of the pupil ($\gamma_1 = 5 \cdot 10^{-3}$, $\gamma_2 = 7 \cdot 10^{-3}$, $\gamma_3 = 10^{-4}$) are selected so that the results correspond to training of the schoolchild, who successfully (that is for 70–80%) copes with the curriculum.

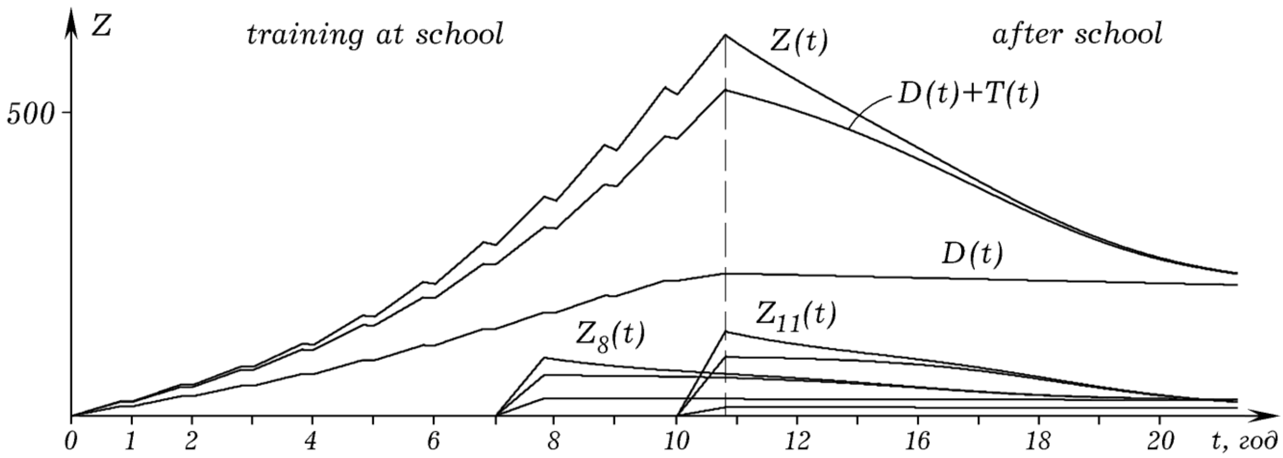

Fig. 6. The modelling results of 11-year school training.

In fig. 6 the graphs $D(t)$, $D(t) + T(t)$ and $Z(t) = D(t) + T(t) + A(t)$, which show the dependence of the quantities of the various categories of knowledge on time are presented. The small failures in the curve $Z(t)$ correspond to summer vacations. It is visible, that after leaving school the pupil forgets the first category of knowledge (used in practice) slowly, and weak knowledge of the third category – fast. On fig. 6 also the graphs of change of the knowledge quantity acquired by the pupil in 8 and 11 classes are shown.

7. Conclusions

In the paper with the help of the imitating modelling method we substantiate the features of assimilation and forgetting of: 1) the poor-associated information, which corresponds to the Ebbinghaus's law; 2) the logically connected materials consisting of information blocks, which include LMEs, connected with each other by logic or associative links. It allows to explain the sharp rise of the understanding level of the studied material happening in the course of training, and also the lowering of the pupil's knowledge level in consequence of gradual forgetting of the separate LMEs. Increase in the knowledge level of all LMEs brings understanding of all information blocks; forgetting of at least one LME causes the pupil's inability to solve the corresponding problem. Some time after the end of training the knowledge level remains high, and then, in the process of forgetting of separate LMEs, it sharply decreases, tending to zero.

These results allow to construct the imitating model of training at school. Along with this we take into account the division of the educational material into: 1) the knowledge used in the pupil's further activity, which is remembered very well (strongly); 2) the knowledge of the various theories, ideas, laws, reasonings, which are well associated with concepts, already studied by the pupil, but not used in practice; 3) the abstract knowledge of separate facts which are not used further and poorly associated with pupil's existing knowledge. The similar models allow to create the computer simulators of educational process (similar to the project simSchool (Gibson, Jakl, 2013)), which can be used for training of the students of teacher training universities and colleges.

The behaviour of the "teacher-pupil" system is the complex and diverse process; we can not take into account all set of the factors, from which its result depends. Certainly, the proposed models of the didactic systems are not describing all possible situations developing at training. The area of applicability of these models is determined by that set of the assumptions, which lays in their basis. The further solution of the modeling problem of training requires a consideration of other factors influencing on result of training, and construction of one universal model or several simple models reflecting separate aspects of functioning of the didactic systems.

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