THE INFORMATION–CYBERNETIC APPROACH TO THE PROBLEM OF THE TRAINING PROCESS CONTROL: THE IMITATING MODELING RESULTS

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Abstract

The development of the simulation method has created the preconditions for application of the information-cybernetic approach for the didactic systems analysis. The present paper is devoted to the creation of the computer model of the cybernetic system “teacher – pupil” which takes into account its structure, the major information flows and the control circuits. It is possible to assume, that the similar model of the didactic system will allow to study the basic features of the training more precisely and will promote development of the mathematical training theory.

The methodological basis of the research are the works by S.I. Arhangel'skij, Ju.K. Babanskij, J.L. Bermudez, V.P. Bespal'ko, R.R. Bush and F.A. Mosteller, M.V. Jadrovskaja, V.M. Krol', A.V. Solovov, V. I. Zagvjazinskij, T.P. Zinchenko, I.A. Zimnjaja, D. Gibson and P. Jakl, R.B. Johnson and L. Christensen, B. Joyce and M. Weil, L.P. Leont'ev and O.G. Gohman, J. Murray, A. Pritchard, V.V. Majer, A.P. Sviridov, B.M. Velichkovskij, J. Wellington. Also we used the system approach, basics of the control theory, pedagogical cybernetic, soft systems methodology, theory of complexity, cognitive psychology, methods of computer simulation.

In the paper the cognitive scheme of didactic process, which is taking into account the major factors and links, influencing on training, is constructed. The mathematical model of system “teacher – pupil”, considering psychological regularities, basic information flows and control circuits, is offered. Thus it is supposed: 1) while training the quantity of the pupil’s “weak” knowledge increases, and a part of “weak” knowledge transforms into “strong” knowledge; 2) the “weak” knowledge is forgotten faster then ”strong” knowledge.

On the basis of the mathematical model the computer program which simulates behavior of the didactic system at various control modes has been created. It contains the cycle on time, which the teacher’s requirements level and the quantity of knowledge, skills and abilities of the learner on the following time step are calculated. The proposed computer model allows to analyze behavior of the system “teacher – pupil”, changing its parameters and the regulation law.

The model takes into account that:

1 at increase of the pupil's lagging behind the teacher’s requirements the pupil’s activity (efforts) first increase, reaches a maximum, and then decrease;

2 at increase of the material complexity or the information speed, at first the transfer coefficient of the communication channel is constant and equal to 1, and then decreases down to 0;

3 the information of the pupil’s condition comes through the reverse communication channel to the teacher with some delay;

4 the teachers can control the training process, changing new information transfer speed or organizing the revision of the studied material.

The article analyses six situations, in which the teacher manages the educational process, adapting to the pupil in this or that way. The graphs of dependences of the teacher's requirements and pupil's knowledge on time are submitted. It is shown, that the results of functioning of the cybernetic system “teacher – learner” are high, when the teacher adapts to the pupil’s possibilities so that learner should apply maximum efforts. There is a maximal speed at which the learner can assimilate the new information; it depends on the pupil’s parameters.

Keywords: assimilation, didactics, forgetting, learning material, training, computer modeling, pupil, teacher.

1 INTRODUCTION

The problem of a reasonable combination of the content-humanitarian and formal-logical approaches for the analysis of educational process has been repeatedly discussed by various scientists and educationists. The formal-logical approach application has resulted in the creation of the mathematical theory of training [1, 2]. It contains a system of axioms basing on results of psychological researches, on the base of which various mathematical models of the training process are created and the consequences are deduced. The development of IT has predetermined the emergence and use of the imitating (or computer) modeling method which consists in writing a computer program, simulating behavior of the system “teacher – pupil”, and realization a series of the computing experiments with it [3]. This approach allows to study various mathematical models of didactic systems (DS) with the help of the computer, to investigate their behavior at various parameters of learners and the distributions of an educational material for finding the functioning regularities and estimation of effectiveness of the various control training strategies [4].

From the view point of the cybernetic pedagogics [5, 6], the processes of training and education can be presented as the management of development of the various qualities of the pupils personality by means of purposeful and coordinated influences on the part of the teacher and parents. Numerous researches (for example [7, 8, 9], etc.) are devoted to various aspects of the training management and mathematical modeling of the didactic systems. For example, the book [10] discusses the following problems of optimum control of the educational process at higher school: the effective curriculum; the measurement of the educational information quantity; the model which links the volume of the learning material presented by the teacher and the knowledge acquired by the pupil; quantization of the educational material; feedback principle, etc.

The article [11] analyzes the computer program simSchool, which allows to model the teacher’s activity during the lesson. At the start of the program the user appears behind the teacher's table in a virtual class filled with the pupils. Each learner (simStudent) is characterized by a set of parameters (or psychological characteristics), which values vary within wide limits. The user, carrying out the teacher’s role, conducts a lesson, asks questions, watches the pupils’ reaction. The program remembers all values describing the pupils’ state over time. At the end of training, the user can analyze the given lesson and look how the mood and activity of the learners have changed. In the book [12] the mathematical model of the transient didactic process is considered.

2 METHODOLOGY

The present paper is devoted to the creation of the computer model of the cybernetic system “teacher – pupil” which takes into account its structure, the major information flows and the control circuits. It is possible to assume, that the similar model of the didactic system will more precisely justify the basic laws of the training process and will promote development of the mathematical training theory. Various aspects of the qualitative and quantitative modeling of the didactic process were discussed in the works by S.I. Arhangel'skij, Ju.K. Babanskij, J.L. Bermudez, V.P. Bespal'ko, R.R. Bush and F.A. Mosteller, M.V. Jadrovskaja, V.M. Krol', Ju. A. Saurov, A.V. Solovov, V. I. Zagvjazinskij, T.P. Zinchenko, I.A. Zimnjaja, D. Gibson and P. Jakl, R.B. Johnson and L. Christensen [13], B. Joyce and M. Weil, L.P. Leont'ev and O.G. Gohman, J. Murray, A. Pritchard [14], V.G. Razumovskij and V.V. Majer, A.P. Sviridov, B.M. Velichkovskij, J. Wellington [15]. Their ideas make the methodological basis of this article. In addition, we use the system approach [16, 17], basics of the control theory [18], cybernetic pedagogics [5, 7], soft systems methodology, theory of complexity [19], cognitive psychology [20, 21], didactics [22, 23], methods of the mathematical modeling of the human behavior [24], methods of computer simulation [25].

3 RESULTS

3.1 The cognitive scheme of didactic process

The model is a material or ideal object that replaces the researched system and an adequately reflects its essential aspects. The first stage of educational process modeling is the construction of its qualitative model, which can be presented as a cognitive network (fig. 1). It is an oriented graph whose nodes correspond to the internal and external factors influencing the learning result – the pupil’s knowledge Z. The arcs with arrows, connecting the nodes, symbolize their interrelations. If the increase of some factor causes raising of another factor, then near the corresponding arc there is a sign ”+”, otherwise – the sign “–“. The result of training depends on the following factors: 1) time, age, grade, year of training t (Time); 2) requirements of the curriculum P (Program) to the pupil’s knowledge; 3) interests, motivation to learning M (Motivation); 4) quantities of efforts applied by the pupils F (Force); 5) coefficient of assimilation α, characterizing the mastering speed of new material; 6) coefficient of forgetting γ, showing speed of reduction of the acquired information; 7) workability W, characterizing the time, during which the pupil is able to work effectively; 8) levels of the teachers requirements L (Level); 9) speed of the new information transfer υ; 10) duration of the lesson or training T (Time); 11) complexity of educational material S; 12) usability of studied knowledge in educational activity and daily life U (Using).

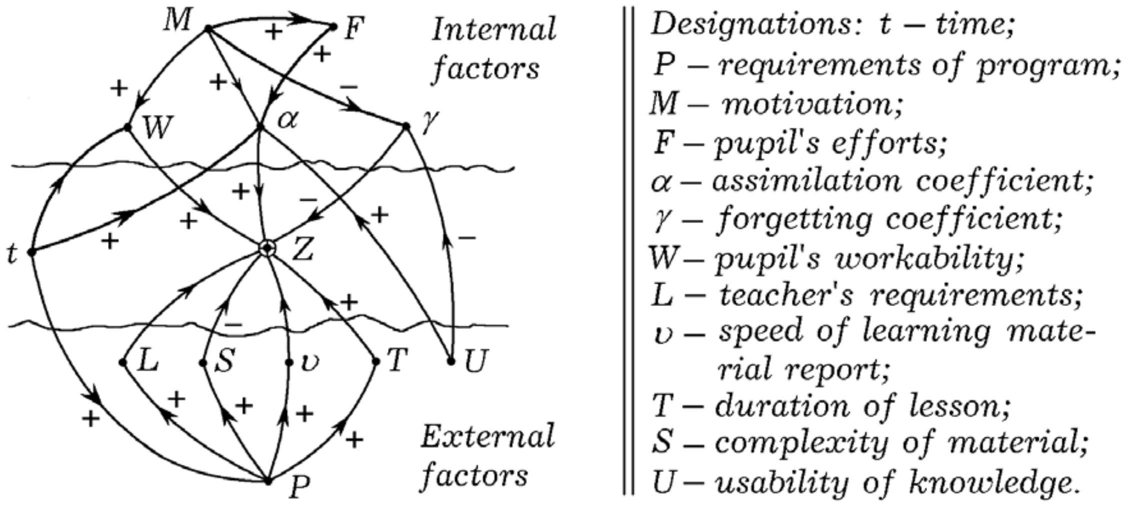

Figure 1. The main factors influencing on the training result.

Near the arcs $P \to L$, $P \to S$, $P \to \upsilon$, $P \to T$ there is the sign “+”; it means, that the increase of the requirements of the educational program P leads to an increase in the teacher requirements level L, the learning material complexity S, the information report speed υ, time of training T. The increase in motivation M causes a reduction of the forgetting coefficient γ, therefore near the arc $M \to \gamma$ there is the sign “–”. The absence of any sign means that the dependency is complex: in some cases influence is positive, and in others – negative. The cognitive schema reflects the most significant factors and links, which are necessary to take into account while modeling educational process. The knowledge quantity Z, acquired by the pupil, also depends on his psychological features, relations with the teacher and other learners, on the quality of the textbook, on ambitions of parents, etc.

While discussing the problem of the exact determination of the didactic system state in the various moments of time, it is necessary to mind **the principle of incompatibility:** the high accuracy of measurements (estimations or prediction) is incompatible with the large complexity of investigated system [26, p. 10]. Indeed, if the object consists of a large number of cooperating elements connected with each other by various links, and is influenced by plenty of random factors, then it is practically impossible to build a model that exactly corresponds to the original. Increasing in the prediction accuracy of the complex system state reduces the reliability of the forecast. Therefore, according to the words of L. Zade, while analyzing complex systems it is necessary “to sacrifice accuracy in the face of stunning complexity” [26, p. 10], as that is required by the soft systems methodology.

Simulation models should correspond the requirement of stability, that is the small changes of parameters of the system, its initial conditions and external influences should not lead to significant changes in the results of modeling. This does not refer to the simulation of abrupt (spasmodic) transitions associated with a sudden “insight” of learner or understanding of task solving after a little teacher’s assistance, etc.

The training is influenced by huge quantity of the various factors, therefore mathematical and computer models of the didactic systems can not essentially be very exact. P.P. Chabanenko analyzing a similar functioning of the human-machine systems, notes, that "not that model is adequate which gives smaller errors in the calculation of indicators, but that one which displays their objective character better" [27, p. 49]. **The adequacy criterion** of the didactic systems simulation models is the conformity degree of character of the model response (that is the pupil's knowledge) to the change of the educational material distribution, the teacher's requirements, the pupil's parameters (that is entrance values), character of objectively existing regularities of educational process.

3.2 The mathematical model of training

The simplified information-cybernetic model of the didactic system (fig. 2.1), consists of a source of the knowledge (the teacher), a receiver of the knowledge (the pupil), that are connected by the direct communication channel DCC (from teacher to pupil) and a reverse communication channel RCC (from pupil to teacher). Let us assume that the studied theme consists of N learning material elements (LMEs), which follow one another. If the teacher requires the memorization of all the educational material, the level of the requirements L is equal to the amount of the reported knowledge Z_0. The complexity S_i of the $i-$th LME is proportional to the quantity of time and efforts required for mastering the given LME. For the most simple LME $S=1$, and for more complex LMEs S are more than 1. The level of the teacher's requirements is calculated as follows: $L=S_1+S_2+...+S_N$. If all N LMEs have complexity 1, then $L=N$. The speed of the information transfer is equal to the quantity of knowledge reported by the teacher per CUT – conditional unit of time $(\upsilon=dZ_0/dt=dL/dt)$, and depends on the requirements level L (or on number N LMEs and their complexity S_i, $i=1,2,...N$).

The result of training depends on the degree of understanding of the learning material. The person understands the information, offered to him/her, if he/she is able to correlate it with his/her own categorical system of concepts [23]. In the learner's consciousness there is transcoding of the coming speech or textual information, its "laying" in their own conceptual system with the subsequent memorization. The more complex is the teacher's statement or formula, written down by him (i.e. speed υ), the more cognitive actions should make the learner to understand it. If the teacher presents a complex material, jumping over elementary reasonings, which represent a difficulty for the pupil, then pupil will not be able or will not have time to connect the new information reported to him with his own system of concepts, will not understand all carried out reasonings.

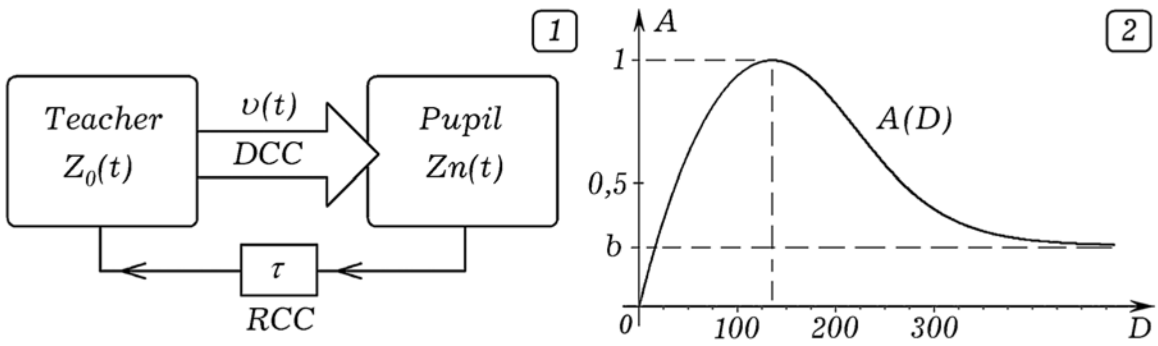

Figure 2. The cybernetic system of training. The dependence $A=A(D)$.

Let us construct the simplified computer model of training. If to neglect forgetting, the speed of increasing of the pupil's knowledge is proportional to his/her educational activity A (or to amount of efforts, which pupil makes in the conditional unit of time): $dZn/dt=\alpha K(\upsilon)A(D)$, where K – the transfer coefficient of the direct communication channel, which depends on the productivity of a source $\upsilon=dL/dt$, $D=L-Zn$ – the difference between the level of the teacher's requirements and the pupil's knowledge. At small υ the transfer ability of the communication channel is equal 1. If the source productivity υ is large then the pupil has no time to apprehend, understand and acquire the teacher's reasonings, therefore K decreases to 0. Let us assume that $K(\upsilon)=1/(1+\exp((\upsilon-12)/4)$. At $\upsilon=12$ CUT^{-1} the coefficient K is equal 0,5. At small $D=L-Zn$ (L unsignificantly exceeds Zn) the pupil's efforts F grow proportionally to size D tending to 1. When D is large, the pupil realizes that he can not acquire an educational material and activity A decreases, tending to some limit $b=$ 0,1 – 0,3. This dependence we can approximate by the function:

$$A(D)=1{,}65\cdot(1-\exp(-0{,}01D))\cdot\left(0{,}15+\frac{0{,}85}{1+\exp(0{,}02D-4)}\right).$$

At $D\to\infty$ the pupil's activity A tend to $\approx$0,25. From the graph $A(D)$ (fig. 2.2) it can be seen that there is an optimum difference $D=L-Zn$, at which the pupil's activity A (amount of efforts in 1 CUT) are maximal.

We take into account, that while training the "weak" knowledge turn to "solid" or "strong" (the skills and abilities are formed) which are forgotten slower [3]. We get the three-component model:

$$dZ/dt=k\alpha_Z K(\upsilon)A(D)-k\alpha_U Z-\gamma_Z Z,\quad dU/dt=k\alpha_U Z-k\alpha_N U-\gamma_U U,$$

$$dN/dt=k\alpha_N U-\gamma_N N,\quad Zn=Z+U+N.$$

Here Z, U and N – the quantity of the learner's "weak" knowledge, skills and abilities (or strong knowledge) accordingly. The knowledge, skills and abilities differ in strength of assimilation (or mastering durability) and have the forgetting coefficients $\gamma_Z=2\cdot10^{-3}$ CUT^{-1}, $\gamma_U=2\cdot10^{-4}$ CUT^{-1}, $\gamma_N=2\cdot10^{-5}$ CUT^{-1}. The assimilation coefficients $\alpha_Z=0.17$ CUT^{-1}, $\alpha_U=5\cdot10^{-3}$ CUT^{-1}, $\alpha_N=1.7\cdot10^{-3}$ CUT^{-1} characterize the speed of knowledge absorptions by the pupil and transition of the "weak" knowledge to the "strong" category. While training $k=1$, and when it stops $k=0$. The result of training is determined by the total level of the acquired knowledge $Zn=Z+U+N$.

The article does not consider studying of any definite subject by a certain group of the learners, but analyzes the situation in the most general form. It is clear, that for different pupils the assimilation and forgetting coefficients strongly differ. In the offered model this coefficients are selected so that the results of simulation correspond to pedagogical practice and common sense.

The given above considerations help to create the model of the pupil. The analyzed didactic system also includes the teacher, who can: 1) present some educational material with the given speed, not paying attention to the pupil (if the feedback is absent); 2) monitor the pupil's condition, and when his/her backlog D exceeds critical value, change the technique of training: organize revision, lower the level of the requirements, reduce speed of the material report (if there is any feedback). The computer program, which simulates the didactic system, should contain the teacher's model.

3.3 Computer model of training and simulation results

On the basis of the considered mathematical model the computer program which simulates behavior of the didactic system at various control modes has been created. It contains the cycle on time, which the teacher's requirements level and the quantity of knowledge, skills and abilities of the learner on the following time step are calculated. The model allows to analyze behavior of the system "teacher – pupil", changing its parameters and the regulation law. It is supposed that the teacher can: 1) report the new information with speed $\upsilon\neq0$, at this $L=L_0+\upsilon\cdot t$; 2) organize revision of the studied material, at this $L=$const, $\upsilon=0$. Let us consider some situations:

Situation 1. The teacher presents some new material with some constant speed $\upsilon=dZ_0/dt$, without taking into account at all the pupil's state. The feedback is absent, an open control circuit is realized. At small speed υ the pupil acquires all the reported information. If the transfer speed of new knowledge is great, the pupil falls (lags) behind the teacher, his backlog D is increased, and at some moment he "comes off" from the teacher (fig. 3.1, $\upsilon=9$ УЕВ$^{-1}$), understanding only a part of the studied material. At the greater speed υ the pupil "comes off" from the teacher even earlier, acquiring even less information.

Situation 2. The teacher continuously monitors the pupil's condition, who, if necessary, asks a question or differently informs that he has ceased to understand the teacher. When the pupil's backlog D exceeds 150 LMEs, the teacher instantly reacts: he stops to report the new information and organizes a revision of the studied material during 20 LMEs. During the revision the level of the teacher's requirements L remains constant, the pupil works with the practical tasks, trying to remember the previously studied information. After that the teacher again begins reporting a new material. The simulation results at $\upsilon = 12$ CUT^{-1} are shown in fig. 3.2, the vertical lines correspond to the moments t_1, t_2, t_3, …, when $D = 150$ LME. At increase of reporting speed υ the system adapts, the pupil asks questions more often, demonstrating his misunderstanding, the teacher has to stop giving of the new material and to carry on revision more often. The average speed of the knowledge transfer does not exceed a certain limiting value which depends on the pupil's characteristics. At small υ (less 8 CUT^{-1}) the pupil has time to acquire the learning material, and the teacher does not stop for repetitions.

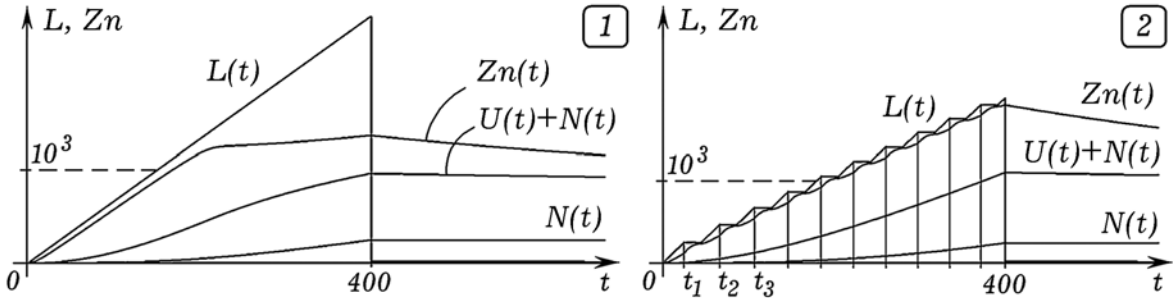

Figure 3. The modeling results of situations 1 and 2.

Situation 3. The teacher continuously monitors the pupil's state, and when the pupil begins to lag behind on 150 LME, the teacher reacts with delay $\tau = 10$ – 20 CUT, ceasing to report the new information and organizing the revision of the studied material so long as D does not appear less than 50. As soon as the pupil reduces backlog to 50 LME, the teacher begins reporting the new material again (fig. 4.1, speed $\upsilon = 11$ CUT^{-1}). The vertical lines show the moments, when D begins to exceed a threshold 150 LME. The horizontal parts of the graph $L(t)$ correspond to revisions of the studied material.

Situation 4. The teacher continuously monitors the pupils' condition, and when the backlog D becomes more than 150 LME (the moments t_1, t_2, t_3, …), he reacts with a delay $\tau = 10$ – 20 CUT. He reduces the requirements level on 100 LME and organizes the revision of the studied material as long as D does not decrease to 50 (fig. 4.2, $\upsilon = 15$ CUT^{-1}). After the revision, the teacher begins reporting the new material with the same speed υ again.

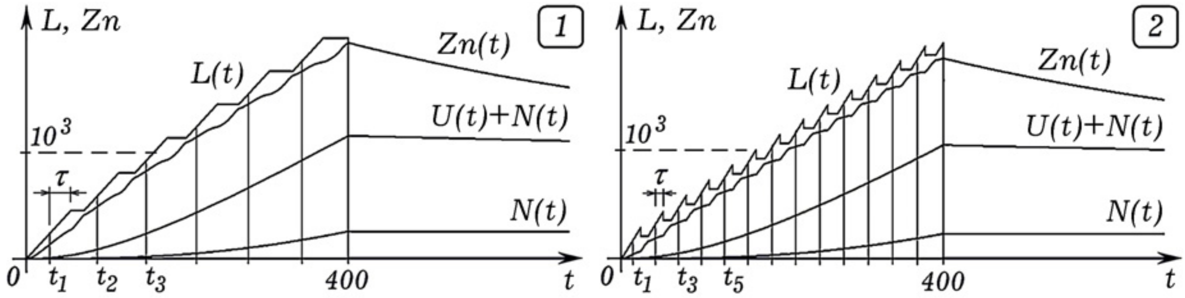

Figure 4. The modeling results of the situations 3 and 4.

Situation 5. The teacher continuously monitors the pupil's condition and when he begins to lag behind on 150 LME, the teacher reacts with the delay $\tau = 20$ CUT. He ceases reporting the new information and organizes revision of the studied material (horizontal sections on the graph $L(t)$) as long as D does not appear less than 50. As soon as the pupil reduces the backlog D to 50 LME, the teacher begins to report the educational material again, but now with lower speed (fig. 5.1). Each time the speed of information report decreases by 2 CUT^{-1}, accepting values 14, 12, 10, 8 CUT^{-1}. This way of control allows the teacher to find optimal presentation speed υ and to adapt to a weak pupil.

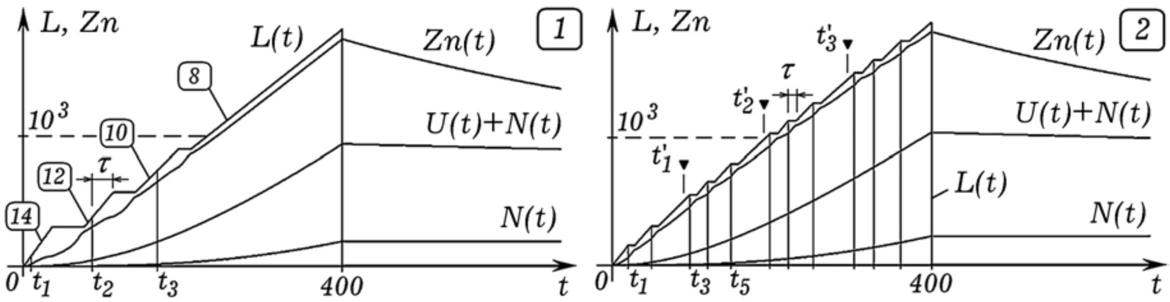

Figure 5. The results of modeling: situations 5 and 6.

Situation 6. The teacher continuously traces the pupil's state. When the learner begins to lag behind by 150 LME (t_1, t_2, t_3, ...), the teacher immediately organizes the revision of the studied material, until D does not appear less than 50. After this, the teacher reduces reporting speed by 1,5 CUT^{-1}. If the pupil acquires all information well and during 40 CUT the backlog D does not exceed 150, then the teacher increases the report speed by 4 УЕВ$^{-1}$ (fig. 5.2). The moments of time t'_1, t'_2, t'_3, which correspond an increase of reporting speed υ, are marked by triangular marks. It is visible, that after one increase of the speed υ three revisions follow accompanied with reduction of reporting speed. The similar control method allows the teacher to adapt both to weak and to strong pupils.

In all analyzed cases, except the first, the cybernetic system with feedback is realized, the teacher adapts to the level of the pupil's knowledge and his/her maximal speed of perception of the new information. Thus irrespective to transfer speed of the information υ by the teacher, the quickness of the pupil's knowledge increase dZn/dt does not exceed a certain limit value determined by the capacity of the direct channel of communication DCC (fig. 2.1). This is in good agreement with the second Shennon's theorem: if the information speed does not exceed throughput of the communication channel (i.e. channel capacity) with noise, there always will be a coding method, at which the message is transmitted with the required accuracy (i.e. the pupil acquires the reported information). It is possible to formulate the inverse statement: if the productivity of a source exceeds the capacity of the communication channel with noise, there is no method of coding allowing to transfer the message correctly. In this case it is necessary to understand coding as "laying" of the reported information by the pupil in his own conceptual system with the subsequent memorization. The role of noise is played by casual processes that hinder understanding.

The obtained graphs and conclusions should be considered as the result of the research of the offered mathematical model corresponding to some abstract didactic system which consists of the teacher and one or several learners. The presented computer model of the didactic system with feedback should not be absolutized: it is fair and correct in that degree, in which the results of modeling correspond to pedagogical practice. The use of conventional units for measurement of time and quantity of knowledge makes the model universal, raises a generality of conclusions. The results of modeling do not allow to develop the specific recommendations for increase of the educational process efficiency, but they complement qualitative reasoning, make them more objective and reasonable. It is especially useful, when the realization of the pedagogical experiment is wrongful or leads to negative consequences. Logicality and formalism, the reproducibility and definiteness of the resulting conclusions favorably distinguish the method of imitating modeling from "qualitative reasoning method".

4 CONCLUSIONS

Though the simulation models, as a rule, have no strict justification, the method of imitating modeling is widely used for studying social processes and behavior of the separate man. This article considers the mathematical and computer model of training process, obtained on the basis of the information-cybernetic approach to the analysis of the didactic systems. Thus it is taken into account that: 1) while training the quantity of the pupil's "weak" knowledge increases, and a part of "weak" knowledge transforms into "strong" knowledge; 2) the "weak" knowledge is forgotten faster than "strong" knowledge; 3) at increase of backlog of the pupil from the teacher's requirements the pupil's activity at first grows, reaches a maximum, and then decreases; 4) at increase of the material complexity or the information speed, at first the transfer coefficient of the communication channel is constant and equal to 1, and then decreases down to 0; 5) the information about the pupil's condition comes to the teacher through the reverse communication channel with some delay; 6) the teachers can control the training process, changing new information transfer speed or organizing the revision of the studied material. The article analyses various situations, in which the teacher manages the educational process, adapting to the pupil in this or that way. It is shown, that the results of functioning of the cybernetic system "teacher – learner" are high, when the teacher adapts to the pupil's possibilities so that he/she should apply maximum efforts. Thus, there is a maximal speed at which the learner can assimilate the new information; it is determined by his/her parameters and does not depend on quickness of the new material presentation.

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