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DEVELOPMENT OF DIFFUSION-LIKE MODEL OF INFORMATIONAL PROCESS OF THE KNOWLEDGE POTENTIAL PROPAGATION

An information model of the city educational environment have been described, the processes of educational qualification growth of the individual from the birth up to full profession readiness and further increment of the knowledge potential have been analyzed. There have been suggested processes of the knowledge potential propagation within socio-communicative environment in the form of the diffusion-like model.

Keywords – educational environment of the city, agent, click, knowledge potential, diffusion.

General statement of the problem

In contemporary information-saturated world, there are global changes in approaching to obtain new knowledge – educational systems are transformed, as well as processes of obtaining and processing information by schoolchildren, students, aged people, persons with specific needs, etc. An appropriate consequence of these events is computerization and informatization in educational processes, implying usage of computing and telecommunicational technological developments, infocommunicational social services, acceleration in obtaining new and strengthening the previously obtained knowledge, information exchange. There is domain closure and socio-psychological adaptation of informative and cognitive educational materials to the eventual user, which applies them for self-learning and professional formation along life-continuous learning. At the same time, along with information society development, streams of information, its processing and propagation speed increase significantly.

This, in its turn, conditions necessity of developing models of informational processes of the knowledge potential propagation, what is going to make possible carrying complex system investigation of socio-educational connections, which, within large socio-polises, are peculiar to such educational structures as kindergartens, schools, technical schools, colleges, universities. That is viewed from the one side, and the other side is business and society, where the goal is to implement the rational common educational, scientific and cultural activity.

A basic socio-communicative structural unit for investigating the mentioned processes has been assigned to urban socio-polis, whose apparent representative is the city, possessing the following conceptual features:

- economic basis (manufacturing-functioning and adaptive pivot of the socio-polis as all-sufficient socio-constitution);
- the advanced sector of social and humanitarian profile;
- the advanced sector of educational and scientific profile;
- functional mechanism of implantation of innovative technologies, etc.

Such choice of the investigation object, which is the contemporary city with spreading and well-developed systems of educational, scientific and business branches, allows developing and processing the corresponding models fully, with minimal restricting factors. If it, particularly, is about education domain, then hypothetically «model prototype of the city» includes pre-school, school, vocational school, higher education institutes, scientific and scientific-research institution, which «produce and consume knowledge actively». In the same time, the obtained modeling results, without any obstacles, may be scaled and propagated out to the level of significantly lesser cities, settlements and other virtual networked socio-

constitutions. Generally, the modeling is suggested to be carried out over systems with number of subjects from a few up to tens of millions.

Analysis of contemporary investigations and publications

Modeling the city development, in contemporary conditions, is an important component of the state management. Increasingly more countries use models of the cities development, for making management decisions, using special software and informational technologies. The city system relates to a class of complicated dynamic systems. One of directions of modeling its development is based on using general physical rules. Therein, it is suggested a wide range of different mathematical models of development of the city territory. In particular, great attention is paid to modeling transport network [1,2].

There are given more and more scientific papers, devoted to application of physical analogies and appropriate laws for modeling informational processes in economic and social systems. Particularly, in the work [3], there were considered formalized decision-making methods in managing social systems, which are grounded on application of Ising's spin models. Usage of methods of physical-mathematical modeling let have defined entropy and have estimated risks of social-economic system functioning [4]. Note that usage of thermodynamic laws showed high level of their appropriateness also in models of managing cities [5].

The results of investigation of informational streams propagation over society are given in works of professor D. V. Lande. Particularly in [5], there is described a logistic model of interaction of informational streams. There are suggested approaches to developing instruments of monitoring, adaptive aggregation and processing the information streams from global computer networks for providing information-analytical activity [6]. There is suggested an original method of wordlet-diagrams for analysis and visualization of informational arrays propagation. With application of mathematical apparatus of cellular automata, the diffusion models of information propagation in social and socio-communicative domains were developed [8].

Scientific works of Lande D. V. make essential contribution into development of theoretical ground and practical decisions for creating methods and means in investigation of informational streams propagation. In the same time, these works don't regard specificities of information processing in the form of knowledge.

The paper goal is to develop a diffusion-like model of informational propagation processes of knowledge potential within educational socio-communicative environment of the city.

Analysis of the findings

Not aspiring to resolution of all problematic questions, and realizing poly-aspects of the subject of investigation, this paper is going to focus on informational propagation processes of knowledge potential within educational environment of the city.

Informational model of educational socio-communicative environment of the city

The city, being a common socio-making constructive element, brings its potential not only for processes of the population reproduction, but stands in the same time the producer and main consumer of educational informational product, which the man gets along the life.

As the basic prototype of the investigation object, there is considered the city with branched network of educational institutions, scientific and scientific-methodical institutions, institutions of post-graduate education of different study forms, scientific-manufacturing enterprises, state and local governments in education. Also there are self-governing centers in education. The city is featured with properties of hierarchical structure, having necessary and sufficient means for reproducing its education-manufacturing potential.

Socio-communicative environment in big cities has a system of interpersonal attitudes between subjects of education-raising process and wide range of different forms of activities, needed for socialization of persons who study due to age and individual socio-cultural requirements and possibilities.

Educational socio-communicative environment of the city is defined as multifarious and polyfunctional formation, which functions and progresses in realtime and definite territorial domain (real

or virtual), whose activity can be controlled and coordinated. And there is made the corresponding pedagogical influence of external objective and subjective factors on subjects of educational process.

Mainly, the wide range of educational processes, streaming in socio-communicative environment of the city, is included conceptually into generalized methodological presentation of notion-terminological triad «INFORMATION – DATA – KNOWLEDGE». In this paper, there are used commonly adopted treatises of these terms. For notion «knowledge», there is suggested to put an additional feature, which allows to fix a rank of the person's knowledge. It is put as a feature of an aggregate, a knowledge integration of an individual, accumulated after the corresponding life cycle. It is proposed to define this feature as «knowledge potential» – φ. The knowledge potential can be imparted as to a real subject, as well as a virtual one – library, informational internet-resource, etc.

Educational environment of the contemporary city is formed and functioning within system of informational streams (flow of the knowledge potential), where, in particular, are processes of creation, mastering and transfer of knowledge from subject groups to others with using computer networks and complexes of information-communicative technologies. An attempt of describing these processes in the form of the appropriate diffusion-like model is a logical corollary in treating on the concept of the knowledge potential propagation.

It is known that diffusion (in Latin, *diffusion* – propagation, dissipation, interaction) in classical traditional comprehension of this term is a process of mutual penetration of molecules or atoms of the one substance among molecules or atoms of the other, what usually leads to equalization of their concentrations above the captured volume. In come cases, one of the substances already has the equalized concentration, and it is spoken about diffusion of the one substance into other [10]. Commonly, diffusion processes by convection and mass-transfer (when inner sources exist) conditions are described as the following differential equation:

$$\frac{\partial\varphi}{\partial t} = D\left(\frac{\partial^2\varphi}{\partial x^2} + \frac{\partial^2\varphi}{\partial y^2} + \frac{\partial^2\varphi}{\partial z^2}\right) - \left(v_x\frac{\partial\varphi}{\partial x} + v_y\frac{\partial\varphi}{\partial y} + v_z\frac{\partial\varphi}{\partial z}\right) + f\left(x,y,z,t,\varphi,\alpha_1,\alpha_1,...,\beta_1,\beta_2,...\right), \qquad (1)$$

where φ is concentration of the substance in the model, D – diffusion coefficient, t – time, x,y,z – space coordinates, v_x,v_y,v_z – velocities of convectional transfer, f is a given function characterizing intensity of the inner sources (pollutions, heat, radiation, etc., depending on the object domain), α,β are parameters characterizing «inner individualities» and outer factors correspondingly. Note, for instance, that in deducing the simpler one-dimensional diffusion equation $\varphi_t = D\varphi_{xx}$, there base is three infinitely close points (see Fig.1 *a)*), where due to «transfusion» from $\bar{x}$ to x the value φ should increase, and decrease relative to $\underline{x}$ and x. If the process occurs along a segment $[0,l]$ then there is considered the continuum of such «triples», as it is known.

Below, in the suggested mathematical model of process of the knowledge potential propagation, when determining dependence of the potential variation for a definite member of the city educational socio-communicative environment, will use common diffusion dependences (relationships). That is, the model will include information concerning neighboring members of a group (collective) of a social community.

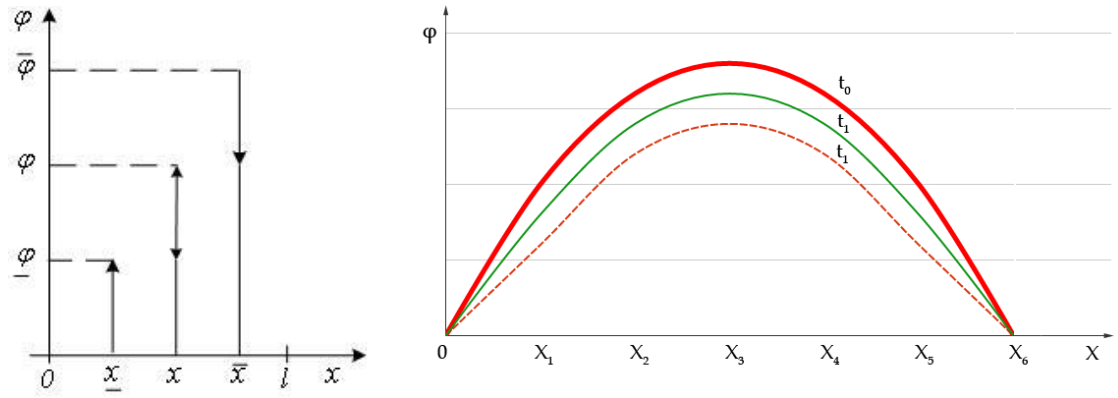


Fig. 1. A common scheme of «diffusive runover» a) and results of computation of the knowledge potential in the initial moment $t_0 = 0$ (bold) and in the moment $t_1 = 1$ by the common diffusion scheme (firm line) and diffusion-like one (dotted line) b)

The city educational socio-communicative environment, in which the knowledge potential propagates diffusion-likewise, in [11] was suggested to be stated as a network graph $G = (A, R)$, where A is nonempty finite set of nodes (agents), R – set of non-arranged couples of different elements from A (relation between agents).

In our case, these agents are pupils, schoolchildren, students, post-graduates, and other persons who study, and also teachers, educators, scientific-pedagogical employees, parents and representatives of business, institutions, enterprises, corporations, public organizations, of the city, which participate in teaching and educational processes.

Relations between agents can be interpreted particularly as «friendship», «collaboration», «communication», «studying» and other forms of interaction peculiar to subjects of educational socio-communicative environment of the city.

Formation of clicks within educational environment over the city schools

Agents within a definite educational level can unite by collective features and properties (for instance, age, education level, studying at the same institution). They form so-called clicks (social communities) $K_j, \left(j = \overline{1,n}\right)$ – subgraphs or classes, having stronger and more numerous connections among nodes of such a class or group than among nodes of other classes or groups (subgraphs) (Fig. 2).

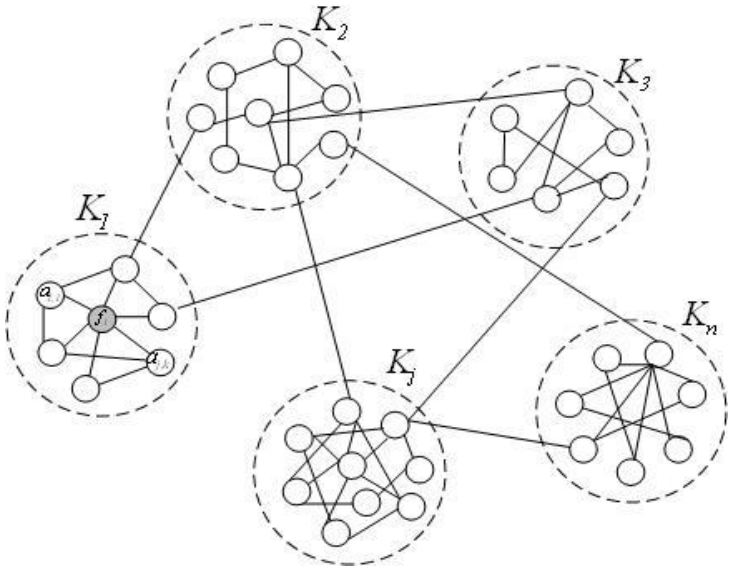


Fig. 2. Sketch of clicks of educational socio-communicative environment of the city at the given educational level

Formation of the corresponding clicks (groups, associations, classes) in educational socio-communicative environment of the city can mostly be held with involving actively modern mobile telecommunicational means. This, in its turn, provides processes of structurization of virtual educational socio-communicative environment technically with minimization of influence of such a factor as physical distance between participants of the educational process, features of the age and specificity of educational requirements of the person. At first glance, an educational social group (click) may include individuals with enough heterogeneous features. The main uniting factor by forming such educational social group and its functioning is necessity of increasing the knowledge potential φ of its participants by a profile and level.

Knowledge can arrive into a definite click (group) as from several physical objects, as well as from «virtual objects». Those objects can be some mobile or stationary gadgets connected to other sources of the knowledge potential.

For example, agents $a_{j,k}\left(j=\overline{1,k},k=\overline{1,k_j}\right)$ studying in the one grade will get the knowledge potential from the teacher in a moment of time. At the same time agents $a_{j,k}$ can be included into subgroup for designing a project on an education subject. Thus, they also will get the knowledge potential while fulfilling that, but not from the teacher, and reading books in library or informational internet-stuff on the tasked instead (Fig. 3).

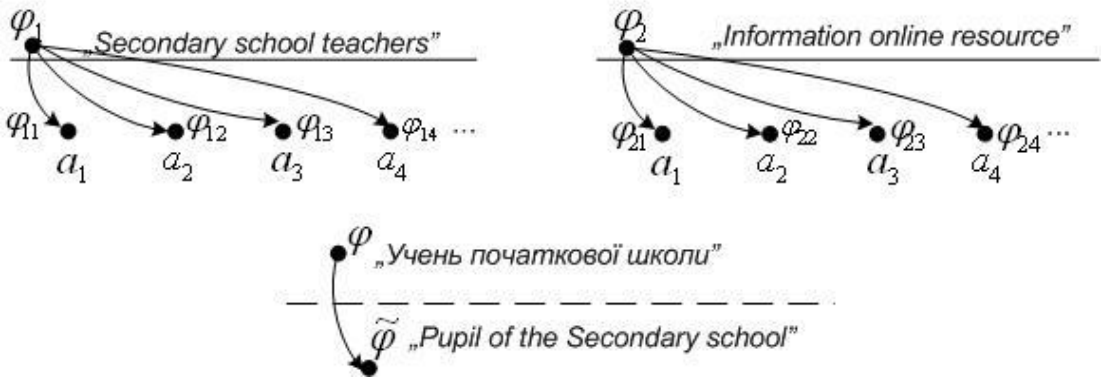


Fig. 3 Sketch of process flow of the knowledge potential

Variation of knowledge potential φ allows subjects of educational socio-communicative environment of the city (pupils of infant school, pupils of primary school, pupils of secondary school, bachelor students, master students and others) accomplish transfer to the next educational or education-skilled level.

Mathematical diffusion-like model of knowledge potential propagation process

In this work, we accentuate description (modeling) of processes of the knowledge potential reapportionment within school educational level of the city. At that, we form the corresponding external and internal dependences among participants (agents) of teaching and educational processes.

In the beginning, let form dependences among agents $a_{j,k}\ \left(j=\overline{1,k},k=\overline{1,k_j}\right)$. Denote by $\varphi_{j,k,m}$ the knowledge potential of agent a_{jk} at time moment $t=t_m$ ($m=0,1,2,...;t_m=\Delta tm$, where Δt is some time interval. Here we put $\Delta t=1$ for convenience.

Within a definite educational level, agents can unite by collective features and properties (for instance, age, education level, studying at the same institution) into socio-communicative communities (clicks). Therefore, diffusion process of the knowledge potential propagation process among agents within some click K_j represented by formula (1) can be stated as:

$$f_{j,k,m}+D_{j,k,m}\sum_{1\le\underline{k}<k<\bar{k}\le k_j}\sigma_{k,\underline{k},\bar{k}}\left(\left(\varphi_{j,\bar{k},m}-\varphi_{j,k,m}\right)-\left(\varphi_{j,k,m}-\varphi_{j,\underline{k},m}\right)\right)=\varphi_{j,k,m+1}-\varphi_{j,k,m}\ \text{ or}$$

$$\varphi_{j,k,m+1} = \varphi_{j,k,m} + f_{j,k,m} + D_{j,k,m} \sum_{1 \le \underline{k} < k < \overline{k} \le k_j} \sigma_{k,\underline{k},\overline{k}} \left(\varphi_{j,\overline{k},m} - 2\varphi_{j,k,m} + \varphi_{j,\underline{k},m} \right) \qquad (2)$$

$$1 \le \underline{k} < k < \overline{k} \le k_j, \overline{k} \ne \underline{k},$$

де $D_{j,k,m}$ is coefficient characterizing the capability of the *k*-th agent in *j*-th educational group to reapportion information (knowledge) in time moment *m* (it's an analogue of diffusion coefficient), $f_{j,k,m}$ – numerical characteristic of the main source of information (knowledge), $\sigma_{k,\underline{k},\overline{k}}$ – some weighting coefficients. Note that the information source can be either single or several assigned agents in some socio-communicative community. For instance, $f_{j,k,m} = \gamma_m \varphi_{j,k,m}$, where

$$k = \overline{k_1}, \overline{k_2}, ..., \overline{k_j}, 1 < \overline{k_1} < \overline{k_2} < ... < \overline{k_j} < k_j$$

(if a click is a union of pupils of a definite profile grade within school educational level then the «knowledge» source is their teacher).

Undoubtedly, a special investigational attention should be paid to building the informational (knowledge) analogue of process of convective transfer (transferring knowledge «from the outside» by other ways). In this work, ways of such kind of knowledge propagation are not investigated.

There are different possible variants of determining the ways of information (knowledge) reapportionment among agents, belonging to the same social community (click), among agent groups of different clicks, and also among clicks within some educational level and, generally, in educational socio-communicative environment of the city (at that, it should be indexed additionally, what corresponds to an educational level).

A variant of introduction of generalized potential of K_j-th educational socio-communicative community $\varphi_{j,m}$ is its representation in the form of a function of $\varphi_{j,k,m}$. Particularly, in the form of generalized average via potentials of agents of the given community:

$$\varphi_{j,m} = \frac{1}{k_j} \sum_{k=1}^{k_j} \alpha_{j,k} \varphi_{j,k,m}, \qquad (3)$$

where $\alpha_{j,k}$ is some weighting coefficient.

Then the law of reapportionment of the corresponding «averaged» knowledge potential among clicks through time can be stated as the following:

$$\varphi_{j,m+1} - \varphi_{j,m} = f_{j,m} + D_{j,m} \sum_{1 \le \underline{j} < j < \overline{j} \le j_k} \omega_{j,\underline{j},\overline{j}} \left(\left(\varphi_{\overline{j},m} - \varphi_{j,m} \right) - \left(\varphi_{j,m} - \varphi_{\underline{j},m} \right) \right) \text{ або}$$

$$\varphi_{j,m+1} = \varphi_{j,m} + f_{j,m} + D_{j,m} \sum_{1 \le \underline{j} < j < \overline{j} \le j_k} \omega_{j,\underline{j},\overline{j}} \left(\varphi_{\overline{j},m} - 2\varphi_{j,m} + \varphi_{\underline{j},m} \right) \qquad (4)$$

$$1 \le \underline{j} < j < \overline{j} \le j_k, \overline{j} \ne \underline{j},$$

where $D_{j,m}$ is coefficient characterizing capability of the *j*-th educational socio-communicative community to reapportion knowledge potential in time moment *m* (it's an analogue of diffusion coefficient), $f_{j,m}$ – numerical characteristic of the main source of knowledge (of the corresponding educational level in whole), $\omega_{j,\underline{j},\overline{j}}$ – some weighting coefficients. Note that the information (knowledge) propagation source can be either single or several assigned educational socio-communicative communities of a definite educational level. For instance, $f_{j,m} = \theta_m \varphi_{j,m}$, where

$$j = \overline{j_1}, \overline{j_2}, ..., \overline{j_k}, 1 < \overline{j_1} < \overline{j_2} < ... < \overline{j_k} < j_k.$$

For the simpler case, the counter influence of values of knowledge potentials $\varphi_{j,m}$ on $f_{j,k,m}$ can be modeled through introducing linear dependence $f_{j,k,m}$ against $\varphi_{j,m}$ ($f_{j,k,m} = g_j(\varphi_{j,m})$, $j = \overline{1,n}$):

$$\begin{cases} f_{j,k,m} = \sum_{i=1}^{n} b_{j,k,i}\varphi_{i,m} = \sum_{i=1}^{n} b_{j,k,i}\left(\frac{1}{k_j} \sum_{k=1}^{k_j} \alpha_{i,k}\varphi_{j,k,m} \right), \\ k = \overline{1,k_j},\ j = \overline{1,n} \end{cases} \tag{5}$$

where $b_{j,k,i}$ are some coefficients, which are found (identified) on the ground of accumulation, formation, analysis and previous experience, fixed in databases.

Thus, due to (2)-(5), for reapportioning the knowledge potentials through time we have:

$$\begin{cases} \varphi_{j,k,m+1} = \varphi_{j,k,m} + f_{j,k,m} + D_{j,k,m} \sum\limits_{1 \le \underline{k} < k < \bar{k} \le k_j} \sigma_{k,\underline{k},\bar{k}} \left(\varphi_{j,\bar{k},m} - 2\varphi_{j,k,m} + \varphi_{j,\underline{k},m} \right) \\ \varphi_{j,m} = \frac{1}{k_j} \sum\limits_{k=1}^{k_j} \alpha_{j,k}\varphi_{j,k,m} \\ \varphi_{j,m+1} = \varphi_{j,m} + f_{j,m} + D_{j,m} \sum\limits_{1 \le \underline{j} < j < \bar{j} \le j_k} \omega_{j,\underline{j},\bar{j}} \left(\varphi_{\bar{j},m} - 2\varphi_{j,m} + \varphi_{\underline{j},m} \right) \\ f_{j,k,m} = \sum\limits_{i=1}^{n} b_{j,k,i}\varphi_{i,m} = \sum\limits_{i=1}^{n} b_{j,k,i} \left(\frac{1}{k_j} \sum\limits_{k=1}^{k_j} \alpha_{i,k}\varphi_{j,k,m} \right) \end{cases} \tag{6}$$

Obviously that this system should be supplemented with some relationships (data) – with analogues of the initial and boundary conditions for diffusion equations (we will make this as the appropriate algorithm of solving is constructed).

Algorithm of computing reapportionment of the knowledge potential through time:

1. Define the specified model parameters included into the system (6).
2. Define the initial state of the system (reapportionment of the knowledge potential by $m = 0$):

$$\varphi_{j,k,0} = \tilde{\varphi}_{j,k},\ j = \overline{1,n},\ k = \overline{1,k_j}\ \ (\sum_{j=1}^{n} k_j \text{ – values}).$$

3. By formulas (3) we compute the generalized potential of K_j-th educational socio-communicative community at the initial time moment:

$$\varphi_{j,0} = \frac{1}{k_j} \sum_{k=1}^{k_j} \alpha_{j,k}\varphi_{j,k,0}$$

4. Due to (5) we find values of the main source of information (knowledge) (e.g., of some chosen educational socio-communicative community in whole) at the initial time moment:

$$f_{j,k,0} = \sum_{i=1}^{n} b_{j,k,i}\varphi_{i,0}$$

5. By formulas (2) and (4) (for $m = 0$) we compute $\varphi_{j,k,1}$ and $\varphi_{j,1}$ and proceed to the next time interval.

As in classical diffusion problems, we will be in want of «boundary values» of the knowledge potential φ (i.e., by $k = 1$ and $k = j$). This brings to necessity of determination of agents' hierarchy within every click of the given educational level (e.g., «teacher-pupil»). Another want is «boundary conditions» for characterizing knowledge potentials of every click. In this case, we have 2 variants to define them:

1) analogously to internal (agents) features, we introduce hierarchy of clicks and define potentials of the «boundary» ones, e.g., we establish hierarchy of schools in a city district, defining potentials of «the weakest» and «the strongest».

2) we will count that clicks are equitable within the educational level; the arrangement is nonetheless introduced in «pure formalism» (not by priorities), counting that $\varphi_{1,\dots} = \varphi_{n,\dots}$, i.e., we define conditions which are analogous to conditions of periodicity (diffusion).

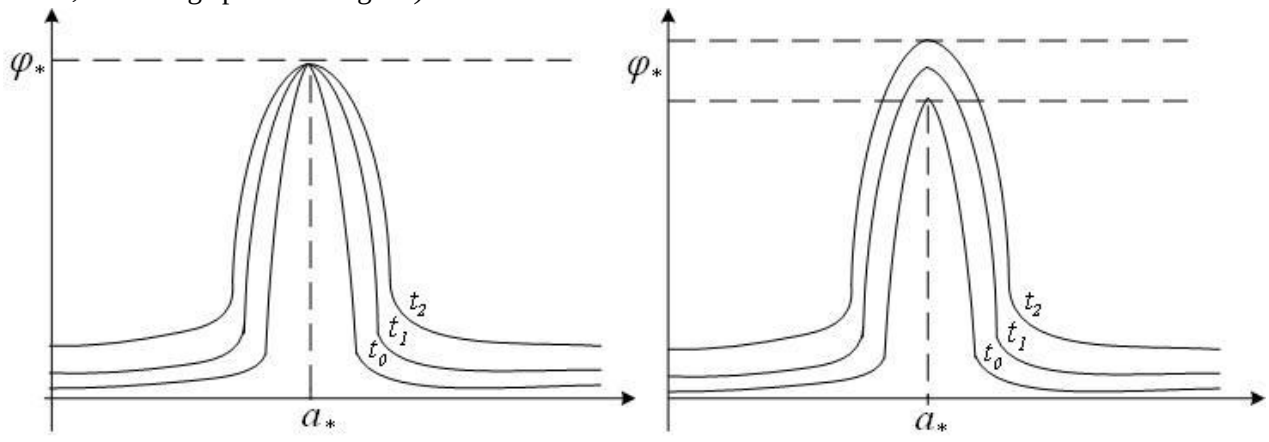
Nevertheless, there are remarks displaying some specificities of applying the suggested approach.

Remark 1. It is possible to consider interaction among agents by the given model, where agents belong to different educational socio-communicative communities, i.e., reapportionment of the knowledge potential through time of the 3rd pupil by the register list of some 10-th grade regarding the influence of the 5-th pupil by the register list of 11 grade in a hypothetical school. With using formula (2) we have:

$$\varphi_{10,3,m+1} = \varphi_{10,3,m} + f_{11,5,m} + D_{11,5,m} \sum_{1 \le \overline{k} < 3 < 5 \le k_j} \sigma_{3,\overline{k},5} \left(\varphi_{11,5,m} - 2\varphi_{10,3,m} + \varphi_{10,\overline{k},m} \right)$$

Remark 2. Underscore again that classical diffusion models for describing the knowledge potential propagation process among agents within a click K_j differ significantly from the stated above diffusion-like models. Particularly, in Fig. 1 *b*) the bold line displays the knowledge potential apportionment at the initial time moment $t_0 = 0$, the firm line displays the knowledge potential apportionment, computed by the common scheme at the time moment $t_1 = 1$, and dotted line displays diffusion-like reapportionments due to formulas (2-5) by $f_{j,k} = 1$, $D = 1$, by interaction surrounding neighbor agents with the given ones, $D = 0{,}1$ – in other cases, $\sigma = 1$, when knowledge potentials of «boundary» agents within a social ring are equal to zero, and their initial apportionment (under conditions of hierarchy) is given symmetrically: $\varphi_{0,0} = 0$, $\varphi_{1,0} = 5$, $\varphi_{2,0} = 8$, $\varphi_{3,0} = 9$, $\varphi_{4,0} = 8$, $\varphi_{5,0} = 5$, $\varphi_{6,0} = 0$.

Remark 3. If the knowledge source is one of the agents within the given educational socio-communicative communities, then with solving inverse problems of model parameters identification (see, e.g., [12, 13]) we can find the value of the corresponding parameter $f_{j,k,m}$ for ensuring the needful informational level of knowledge of this agent-teacher – e.g., due to Fig.4 *a)*, that the vertex of the outgoing curve would be changeless through time or be within some interval by the condition of the low initial, knowledge potential Fig.4 *b)*.



a) *b)*

Fig. 4. Sketch apportionment of knowledge transfer by the agent-teacher a_* under condition of stability of its knowledge level through time

Remark 4. Having the previously computed knowledge potential φ and introducing the specific values of potentials, e.g., of teachers $\tilde{\varphi}_0$, of «excellent» pupils $\tilde{\varphi}_1$, of pupils with «good» $\tilde{\varphi}_2$ and

«satisfactory» $\tilde{\varphi}_3$ knowledge, the comparison of them to the obtained values $\varphi = \varphi_{j,k,m}$ allows to plot the equipotentials of knowledge l_0, l_1, l_2, l_3 respectively, which are lines of partition of educational sociogroups (layers) within the *j*-th click (see Fig. 5, where $\tilde{a}_{j,k}$ are characteristics of agents due to the corresponding re-indexing).

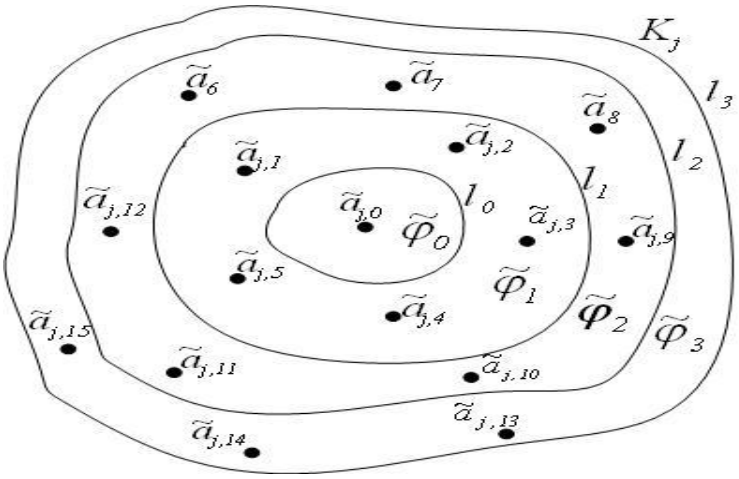


Fig. 5. Schematic display of equipotential lines formation of educational sociogroups partition

Conclusions

Educational environment in socio-polis is formed and functions over system of informational streams, where processes of knowledge formation, mastering and transfer from one subjects to others take place, based on modern communication networks and complex of information-communicative technologies. Namely, building models and modeling the informational propagation process of knowledge potential will make possible carrying complex system investigation within large socio-polis in its socio-educational connections peculiar to such educational structures as kindergartens, schools, technical schools, colleges, universities. That is viewed from the one side, and the other side is business and society, where the goal is to implement the rational strategy of common educational, scientific and cultural activity.

The authors suggest the informational model of the city educational environment. They analyzed education-skilled growth of the person beginning from the birth up to full profession readiness. There has been proposed an original model approach to informational processes of the knowledge potential propagation based on the corresponding diffusion-like model. There have been described processes of the knowledge potential reapportionment among agents, belonging to the one educational socio-communicative community (click), and also among agents of different clicks within a school educational level of the city. The authors have developed the algorithm of computing reapportionment of the knowledge potential through time.

Further investigations are going to be directed towards developing mathematical model for processes of the knowledge potential reapportionment among communities of different educational levels under conditions of the city socio-communicative environment.

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