NDM-PHILOSOPHY OF EDUCATION IN THE 21st CENTURY

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The main ideas of this talk are presented in the book [1]. Due to the interest of experts in pedagogical psychology and mathematical modelling, the book has undergone several editions, in Bulgarian, Russian and English including. In 2017 one of the English variants appeared [2]. The English title is a translation of the Bulgarian one from above. I would like to underline the contribution of the first author Prof. Marga Georgieva who we lost unfortunately some time ago. The last version of the talk was prepared with the courteous cooperation of Prof. Veselin Nenkov, a past PhD student of the second author. The title of the book contains the words "morphodynamics", meaning an aggregate of the changes of a developing organism (in Greek *μορφήμ* means form) and "noosphere", meaning sphere of the mind, a special state of the biosphere with a key role of human beings (it is the result of the evolution in the chain "Planet development – biosphere – man's birth – noosphere's birth as a second "Nature" together with the existing one").

A constant task of education is to provide possibilities to the system "Trainer – Trainee" toward optimization of the development of the intellect, which becomes necessary for the contemporary technological society. This requires restructuring of the system by uncovering and describing the regularities of the learning process through the knowledge of didactics and it could happen in horizontal and vertical sections. On this basis, we are led to the demand for an interdisciplinary approach in the development of a uniform methodology for the applications. We believe that mathematical modelling brings an optimal management, resulting in opportunely discovery of changes in the cognitive activity of trainees through mathematical models. They are determined by the functions performed and have not only the task to receive new information but also to check to some extent the accuracy of the already available cognitive information. In other words, mathematical modelling is the intermediary link between theoretical and empirical study methods. It enriches the objective reality and therefore, the system "Trainer – Trainee" under investigation should be considered in the context of optimal development of the intellect throughout lifelong learning. The main criterion for its effectiveness is contained in its abilities for anticipating, planning and forecasting, which are reflected in abstract mathematical models through real activities. It is often very difficult and sometimes even impossible to maintain some factors in a constant level while

mathematical modelling can play this role under certain conditions. The scientific and technical evolution of the modern society turns it into the main content of creative operations in various processes, including the development of the intellect, categorizing it as a typical activity of learners or their trainers, thus rising the intellect into a higher and substantially new level. Too many hopes are reposed in the opportunities and even the overall achievements of knowledge.

The system "Trainer – Trainee" is characterized by:

- stochastic nature of the learning process;
- a multi-factor organization and performance;
- continuity of the relationships between its predicates, operations and functions;
- negligible driftage of research on many of its characteristics, leading to the modelling of stationary objects (repetition of the studied addictions throughout time);
- controllability of many of its features, which is expressed through effects on the object in order to achieve the best possible results.

Although in recent years, the didactic trends for optimization of the learning process appear as dominant in the pedagogical literature, there is still room for improvement in the corresponding theoretical and practical justification. The already created related concepts formate a valuable theoretical foundation that can serve as a guideline in the individual actions for an effective functioning. At the same time, there are a number of weaknesses associated with the inductive approach justifying the predicates, operations and functions of the system. The idea of optimizing the structure by modelling (appropriate for didactic purposes) would significantly refine its composition, functional interaction of the components in solving many educational and cognitive problems that are pedagogically appropriate and are satisfying the needs of the training.

The need of applying mathematical modelling in training is imposed by:

- the requirements to prepare learners and their accelerated adaptation to specialties which are also related to more appropriate use of technologies of teaching and learning;
- the achievement of the highest quality of training in the least possible time and the greatest economy of material and intellectual resources – only possible on the basis of effective modelling and forecasting;
- the placement of forms and methods of teaching at optimum in accordance with the growing volume of scientific information on the formation of specialists.

It is difficult to answer the question what mathematical modelling constitutes a tool of study, what are the common and essential features, which express its essence. The requirement is that there is a certain similarity, likeness, correspondence between two systems, one of which is a model to the other. However, that relationship between them is a unity of diversity and identity, indicating that modelling excludes complete diversity as well as complete identity. The results obtained from it are generally transferable with some probability from the model to the object. They extrapolate to the object. Let us denote with (X, Y, Z) the mathematical structure (X – basic concepts, Y – relations and operations, Z – mathematical statements), which will shape the processes and phenomena of the system "Trainer – Trainee". The main requirement when using this structure is the information that will be processed to meet the conditions:

- to refer to many;
- to allow quantification. In this case, the mathematical model (X, Y, Z) and the phenomenon/process of the examined system are isomorphic. Achieving this isomorphic realization is the essence of mathematical modelling. We distinguish its two stages: building a mathematical model and the solution of the mathematical problem, i.e. processing information, which we extrapolate on the original. It should also be noted that a mathematical model as a method of study has two levels (traditional and computer due to the probabilistic nature of the system) and requires an implementation on the second level.

There will always be unresolved problems. This is the privilege of the future. We allow ourselves to offer a new term of the complex concept NDM, given the synergetic principle in which it is postulated that all is characterized by properties that are not identical with the properties of the parts of the system as a way to something new, informative for a new structure of the test system using the known concepts eidetics, reflection, synectics, synergetics, enigmatics, akmeology, creativity, cognition, emotion, motivation, etc. The new term of the complex concept means new dynamic modification (a short version written in Latin – "neodinmod" and even a shorter version – NDM). However, here it is worth noting that the new paradigm offers the highlights of the study to be directed toward a methodology and specific techniques for harnessing the power of thought. These techniques are aimed not only at the early age students, but also in adult ones as well and addressed to akmeological trends, which lead to a higher level of individual development of the intellect. Naturally, the goal is the optimal adaptation of the intellect to changes in the external environment in order to improve its ability to maintain consistency of its internal environment, i.e. the homeostasis.

Is it not a temptation to accomplish in this way a triumph of positive cognitive transformations in the internal act of the intellect, which in one way or another, will provoke its dormant genetic potential and will orient it toward innovation – toward transition from extensive to intensive development path. In line with that, we offer to the researchers that work in this direction to try and seek identification of the above-mentioned term with the definition of the new complex concept in the proposed paradigm and why not upgrade it with new versions in the future.

This, of course, requires a combination of global discussions on topics such as:

- the technological environment, which in the NDM-paradigm is named after the NDM-environment, since it covers all learning environments, plays an essential role as a foundation in morphodynamics;
- the aim at complying with the processes of continuity between the generations of the past and the present;
- the need for development of the intellect in the current and future technological society facilitating the ever increasingly complex integration in various scientific fields.

Such statements require continuous amendment of the numerous educational paradigms with an emphasis on giving a central place above all not to the evidence, but to the cognitive aspect of science in order for the optimal development of the learners' intellect in each age to be reached faster. This is the way for uniting the contemporary generation (having into account learners) toward the constant changes in the education system in the context of the high technological space of the future. As referred to here, the morphodynamics (external and internal) stays at the foundation of NDM-paradigm.

What does it mean to introduce a new concept? In accordance with the requirements of the procedure, its definition includes volume, content, term and definition. As a complex concept NDM combines the concepts of eidetics, reflection, synectics, synergetics and others that will be mentioned in the sequel. Its volume covers all objects whose essential properties reflect the synergetic principle – the whole reflects the properties of the parts, but the parts reflect the properties of the whole and in fact, it is not more complicated than they are but contains quite different properties. The content of the NDM concept encompasses the general and essenial properties of the objects involved in its volume. The term is the common name/designation of the objects of its volume. The definition is the sentence, which indicates the contents and the term of the concept. We will clarify some of the notions that are included in the NDM volume.

- **Eidetics** – the essence of this concept is to merge different ways of developing the sensorimotor anticipatory resources of the intellect by the

presence of descriptive conceptions. However, the practical eidetics represents interest, some authors call it "morphodynamics" (for example [3]) and properly treat it as "an integral science" to build a universal system of anticipatory relations such as images – actions – images regardless of the scope. The specific sensorimotor ideas and concepts, that are built this way and are enriched continuously, are at the basis of the understanding and utilization of relevant processes and laws in every area of development of science.

- **Reflection** is a major phenomenon of the internal activity of the subject, and therefore includes perception, analyzing, understanding and reflection regarding their own actions and mental states. It is usually associated with self-exploration and self-assessment by the subject of its respective actions and relations in the context of cultivation of the personality. According to what was said about reflection, reflective abilities are complex personality formations, revealing opportunities for proper understanding and assessment of oneself by the subject when taking the necessary decisions. The allegation, that reflective thinking is a superior cognitive mental process as a base of reflexive abilities, is true. In the most general plan, reflection is one of the most important mechanisms for stimulation of the mental abilities, respectively the cognitive interests of the trainees. In the context of NDM, we are interested in the inner experience of the subject, which is essential for the manifestation of reflection.
- **Synectics** [4] characterizes the relationship between the rational and emotional beginning in every human activity and stimulates creative thinking. Moreover, several authors associate it (for example [5]) with the method "group search of ideas", which is based on the properties of the brain to establish associative links between objects. Usually this method focuses on analogies as tools for indepth analysis in solving various problems and puts the subject in reflexive position of the activity. Synectics includes the relation between the rational and emotional, which leads quickly to the activation of reflection.
- **Synergetics** explores the collaborative action of multiple subsystems with a focus on internal properties as a source of self-development and because of that, a new operating system with a new structure comes into being. Some authors (for example [6]) consider it a science that determines the general laws of self-organization and cooperation of the various subsystems [7]. Self-organization as a foundation of the synergetics is the science of mathematical modelling of the transition of the system from one stable state to another. There are different approaches to describe the self-organization – synergetic, thermodynamic, dynamic. Some of the key concepts and ideas

underlying the foundation of synergetics are: system, structure, self-organization, chaos, order, fluctuation, bifurcation, attractor, phase space, row parameters, control parameters treated in many publications, domestic and foreign. Naturally, the main synergetic idea is related to the self-organization. Some necessary and sufficient conditions for its functioning are: complexity, openness, disbalance, probability, coherence. A number of already existing synergetic ideas are very concentrated in the principles formulated by G. Budanov [8]. They are very important part of the methodology of synergetics and are kept in mind in the NDM, which leads to new row parameters and as such we can call it (the NDM) a "symbiotic" concept that has a priority in shaping the noosphere personality system "trainer – trainer". An example of a synergetic model of the learning process is discussed in the sequel.

Let us denote the preparation with $P(t)$, that is offered and carried out in the interval $[t_1;t_2]$ with a group of pupils or students. In particular, $P(t)$ could mean self-preparation including learning by one's own, reading a book, working in the library, etc. It may include or may not include scientifically and methodologically based system of knowledge with theoretical and practical character, as well as creative efforts of teachers. In general, in the theoretical aspect there is no limit to the type and values of $P(t)$. Broadly speaking, $P(t)$ is the external effect, which is aimed at the learner or which the learner directs to himself/herself (i.e. the so-called external morphodynamics is at the basis). Let us suppose for a moment that $P(t)$ is the "ideal" effect from the aspect of standards, proper method and scientific characteristics, providing with a quality teaching staff, etc. In case it is not influenced by external factors, i.e. the so-called noises (what we understand by noises is the momentary mental state, health indisposition, material status of students and teachers, technical equipment, etc.), $P(t) = P_0 = \text{const}$ for the considered interval. We call the interval $[t_1;t_2]$ itself learning stage or stage of preparation. It is clear that $P_0 > 0$. In the first approximation, we assume that learning is "pouring" of knowledge and skills, i.e. it is a "filling of a vessel". In this case learning is described by the equation $k'(t) = P_0$, $k(t_1) = k_1$, where $k(t)$ is the unknown level of the preparation reached during the educational process. From here we find $k(t) = k_1 + P_0(t - t_1)$ and $k(t_2) = k_1 + P_0(t_2 - t_1)$. This result shows that gaining experience as a result of learning is proportional to the length of time interval $[t_1;t_2]$. By analogical calculations, we can reach the same conclusion in the case when preparation (learning) is influenced by external parameters depending on time, i.e. $P = P(t)$. Again, the level of the potentialities turns out to be proportional to the time interval and is increasing at a greater interval. In the second case – that of course is true at the natural condition $P(t) > 0$. It turns out that the greater the length of the interval, the more the acquired knowledge, skills and others. However, this is not true, at least because of the undeniable fact that

all learning is uneven, whether we are talking about perceptual motor learning, about associative or some other kind of learning. The dynamics of learning and the so-called learning curves, studied in depth by Gencho Piryov in his monograph [9], convincingly demonstrate that the process of learning is directed upwards. It is characteristic that at the beginning the perception is much slower. The reason for that is the need for adaptation as well as in realization of new situations or new concepts and techniques, if there are any, etc. Fast initial perception is also possible. It may be caused by a sudden insight, by the absence of unknown facts in the beginning, by a strong motivation and others. The American psychologist Edward Thorndike calls this "negative acceleration". Regardless of differences in initial speeds and accelerations, in all of these cases there is a development. We cannot talk about learning without any development of the participating processes. This is why development is one of the hallmarks of learning. The attempts of G. Piryov by placing cats in a cage, his studies of people with the help of the Decroly's puzzle boxes and a number of observations indicate that from the lowest forms of learning by trial and error to the highest manifestations of the human spirit psychic processes develop in the same ladder. This ladder has been climbed by the biological world, and it outlines all mental events, despite their diversity. From the inspections made, it follows that the process of learning and preparation cannot be equated with "filling of a vessel". Thus, we conclude that the principle of superposition is not applicable, i.e. not everything that is studied, is learnt. Therefore, the process of learning is non-linear. The development of psychology, including the development of mathematical psychology over the past 70 years, and especially the theory of education, shows that it is wrong for the role of trainer to be absolutized. The participation of the trainer himself/herself is crucial to the training. In 1885 the famous psychologist Hermann Ebbinghaus, exploring the memory of the man, carried out a very attractive experiment as a result of which it appears that in different individuals remembering and forgetting of a series of words follow the same principal. In the 80s of the 20th century, psychologists have proved something else: the acquiring of complex habits has a threshold character. In mathematical education, this means the following: after a certain number of hours of activity during which a certain amount of problems are solved and practical exercises are conducted, the trainee acquires a qualitatively new level of preparedness. If, however, this critical point (plateau) is not passed, then after a while a process of forgetting begins and the efforts made in the learning turn out to be pointless. The situation looks like the case of that literary hero who began to read a book, got up to page 30 and fell asleep. The next day he began the book again, but on page 30 or about he fell asleep again. The story has repeated for a few days. The analogy with lighting coals in quite interesting. If the coals are heated up, even for a long time, to a not so high temperature, they do not light up. The same is observed with intense but brief heating. If the heating is appropriate, the coals get lit, radiating heat and light. The same goes for learning. Radiation of "heat" and "light" which is determined by the presence of high (or

enough) results during periodical exams and tests, for example before an exam, is a proof that the trainee (learner) has passed the critical threshold and learning has been effective. We have an example of a typical non-linear process. Except for the mentioned lighting of coals, another analogue is the nuclear reaction. The explosion at a nuclear reaction occurs only in the case that a certain amount of critical mass has been accumulated. If the graph is observed – Thorndike's "negative acceleration" is observed in the solution of the above-mentioned differential equation with a variable right side. The reason for its occurrence is that the beginning of the curve is determined by examination (periodical exams and tests), which causes a serious motivation itself.

The most general form of the equation in case that it is solved with respect to the first derivative (the speed of learning), is as follows: $k'(t) = F(t,k)$, $k(t_1) = k_1$. When the function $F(t,k)$ is non-linear, the equation describes a non-linear dynamic system and is therefore suitable to be used in modeling of learning. This is done in [10], where there are some approximations of $F(t,k)$ and k (t) is examined. It is important that the functional dependence $F(t,k)$ takes into account the active role of the learner in the learning process.

The change in the level of preparedness, which is described by the graph of the above-examined differential equation, depends on the initial condition $k(t_1) = k_1$. The point with coordinates $(t_1; k_1)$ is the beginning of the curve. Because the graph models a real process, we will explicitly note that the beginning of the curve does not coincide with the absolute beginning of the process. This is because when the trainee begins to study a subject, in fact he/she starts not from scratch but from a higher point. This is due to some knowledge in the implementation of a job, so we cannot determine exactly when a particular ability that we want to explore is acquired. The modern conception of learning as well as for training and education as a whole is that it is a matter of a deterministic process, i.e. a process with a background that has a crucial impact on the process itself. This does not mean that history determines the future. For almost two centuries, influenced by Newton's classical mechanics, science has believed the opposite. The so-called determinism was dominant, which is also known as Laplace's demon, named after the most prominent exponent of the absurd from the modern point of view claim that if in the moment t_1 the position and velocity of every particle of the Universe is known, the future can be accurately predicted according to Newton's law for the arbitrary $t > t_1$. The philosophical thesis from the time of Laplace follows from here regarding the fate of human development, particularly of his/her education and his/her level of preparedness. Only in the early twentieth century, the famous mathematician Poincaré says the words: "The determinism is a fantasy of Laplace.", and thus condemns the error of his compatriot Laplace. The insight of Poincaré is conditioned by several important observations, one of which is connected again with the name of a Frenchman –

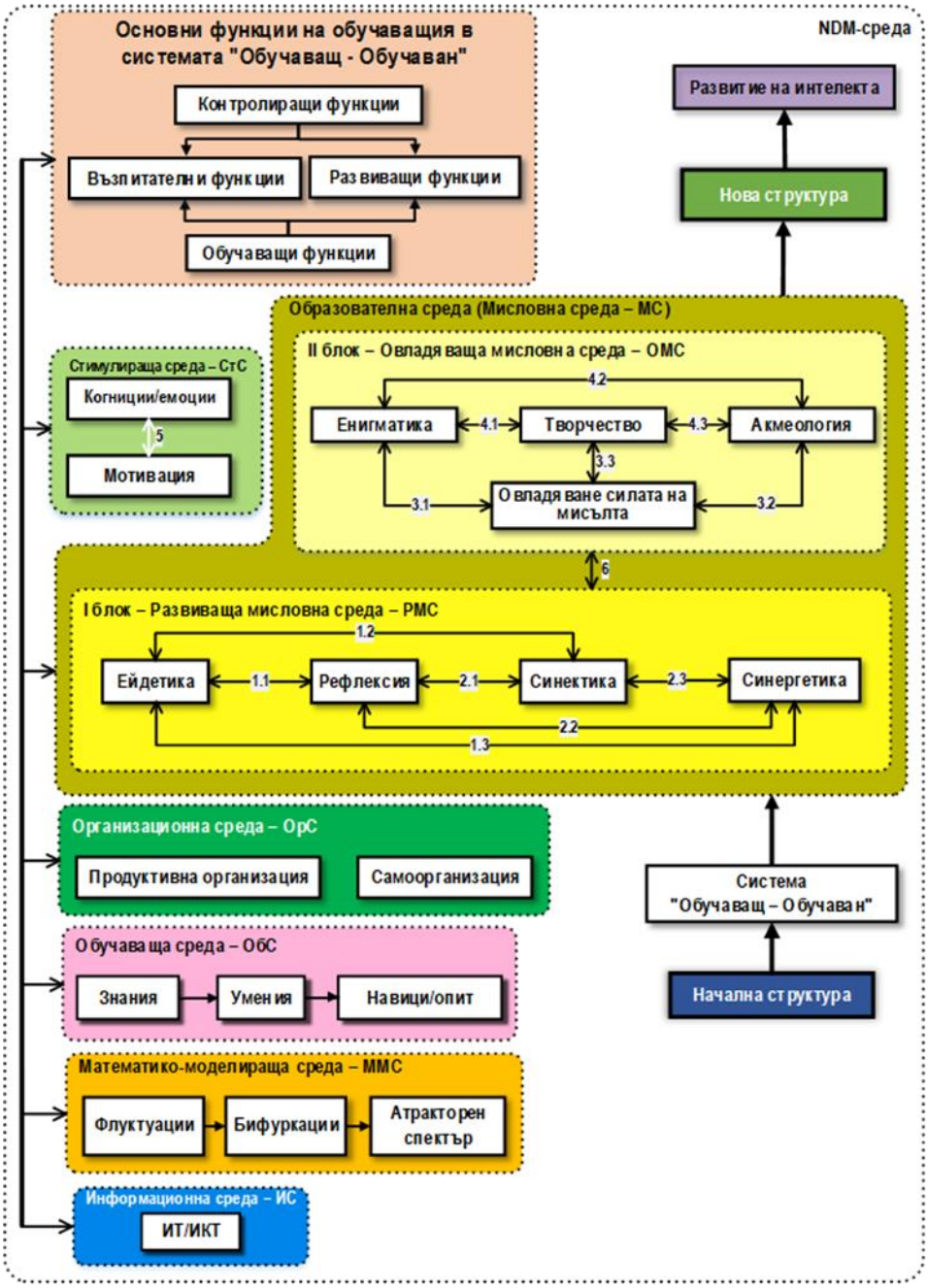
Jacques Solomon Hadamar (1865÷1963). He noticed that unlike the rectangular or circular billiard table, the one of which the sides are arcs of circles with centers outside the table is too "sensitive". Two very closely situated balls on it, after being pushed simultaneously in the same direction with the same initial velocity, start to run by completely different trajectories after a few hits in the walls. Regarding the sensitivity Poincaré considers that small differences in the initial conditions can lead to large differences in the final effect. This leads us to believe that in order to qualify the behavior of a non-linear system as chaotic, there must be at least the following signs: the system is deterministic, i.e. there is a rule that defines its future behavior given the initial conditions; the system shows a strong sensitivity to initial conditions (making it generally unpredictable, or rather with limited predictability).

Being convinced that learning is deterministic, we are left to be convinced of its sensitivity. If $x(t)$ is the volume of stored material, the classical experiments of H. Ebbinghaus show that $x(t) \approx C_1 - C_2 e^{\alpha t}$, where C_1 and C_2 are constants, and α is indicator of the speed of perception (forgetfulness) with $\alpha > 0$. If at first approximation the function $F(t,k)$ has the form $F(t,k) = F(k) + P$, where $F(k) = \alpha k$ takes into account the active role of the learner, then $k(t) = -\frac{P}{\alpha} + \left(k_1 + \frac{P}{\alpha}\right) e^{\alpha(t-t_1)}$. The resulting expression strikingly resembles the expression of Ebbinghaus. The one is derived experimentally, and the other – purely theoretically. The decision has a critical point beyond which a plateau appears and the so-called zone of saturation occurs (in the terminology of G. Piryov [9]). The plateau comes under the class of long-lasting (continuous) fluctuations in the proposed classification of fluctuations of the learning curves. Less or more continuous horizontal or almost horizontal direction of the curve, which is followed by a new faster or slower elevation, is namely plateau. In the brief fluctuations, there are short elevations or declines observed. This principle consists of the fact that constant declines and elevations are necessary elements of any learning. Every elevation is followed by a short rest period, which in turn is a preparation for the next elevation. The fluctuations (short-term and longterm) are due to the gradual change of the so-called control parameters. The indicator α in the function of H. Ebbinghaus plays the role of a personal parameter, and its analogue in our dynamic model characterizes the solution. It is an example of a controlling parameter. Various authors focus in detail on the methods for experimental determination of this parameter. Such a method was developed by us in [11] but we will not focus on it here.

The solution of the linearized equation with a fixed α is a monotonously increasing function, because its first derivative (the speed) is positive and in this respect, does not differ from the above-mentioned learning curves of G. Piryov. Comparing the curve – solution of differential equations and curves of G. Piryov

shows two differences. The first one, we believe, is negligible. It is due to the property "smoothness". In one case, the curve is "smooth" and in the other, it is not after being derived by "gluing" of sections. All curves of G. Piryov are "broken lines", i.e. lines formed by line segments, because they are obtained experimentally and "horn points" (points of connection of two segments) have ordinates, which are measured values. Our curve is a continuous model of the learning process for a given time interval, while with G. Piryov the models are discrete. The main trend (rise of learning) is visible and this allows us to determine that difference as negligible. It is another issue which curve is more usable. In defense of the laboratory approach, we will only say that one month before an exam or a serious mathematical contest when there is intensive preparation, we cannot afford daily tests or periodical exams, via which we can monitor the amendments in the level of preparedness. A similar monitoring is important. Of course, one or two measurements in the learning process are appropriate for verification of theoretical changes in the level of preparedness and to maintain a "competitive" tone. The second difference, however, is essential. We have already noted that the curve of the theoretical model is obtained at a fixed α. The logical explanation for the fluctuations in curves of G. Piryov is change in α. Any new knowledge in this case leads to the acquisition of other knowledge. We have an example of fluctuation which is typical for non-linear processes. In the learning process for a specific stage of training (learning), the trainee enters his/her own specific value of α. At that moment his/her system of knowledge, skills, habits, talents, abilities, etc. is in an equilibrium position. The system, however, is extremely sensitive. Even the smallest new information affects it and it begins to fluctuate. The relevant α changes and this corresponds to the fluctuations of the learning curves of G. Piryov. The change in the controlling parameter α is smooth in the direction of increase or decrease, passing through the exit position, again increase or decrease, etc. From a constant controlling parameter, it becomes a variable one. The variable is key. It defines the system's state. It is possible to reach another value of α. In this case, the learner passes from one qualitative state to another. The specific $\alpha_1, \alpha_2, \ldots$, etc. characterize the sustainable equilibrium positions, while the intermediate values characterize the unsustainable equilibrium positions. The state between two sustainable positions is a state of non-orderliness (chaos). But this is not non-orderliness in the literal sense. Haken [6] rightfully calls it deterministic accident or order, disguised as an accident. In fact, through the chaos, the system "seeks" sustainable states and in the presence of opportunities, it replaces the old steady state with a new one, which is of a higher order. The seeking looks like wandering, but it is strictly conditioned and inevitable evolution of the system. It even turns out that it is useful too.

The NDM environment is shown in the next scheme:



Our research shows that even small changes (fluctuations) lead, to some extent, to great differences in the future state of learners. The findings of determinate and undetermined chaos are at the heart of NDM, as one of the key concepts is synergetics). This means that by studying the intellectual development of men, including learners, we cannot ignore the self-organized formation of the educational system under consideration, i.e. the "Trainer – Trainee" system. In the context of NDM, the attention is more focused on non-equilibrium phase transitions. Considering the fact that the probability is an inevitable expression of chaos, there is a need for the concepts we are dealing with: eidetics, reflection, synectics and synergetics, which have already been mentioned above, in order for constructive chaos to be reached faster – an important moment of evolutionary development. Synergetics is the one that supports the "I-concept" of mathematical

modelling and from its point of view longlife learning needs non-linear models in order to clarify non-linear thinking (including co-thinking) as unusual, probable and creative. The goal is to achieve an optimal outcome in the homeostasis. In each of the phases of longlife learning, regardless of their knowledge, skills, habits/experiences and abilities, the learners at a certain point meet chaos (sometimes unable to solve the corresponding problem). There appears to be a need for micro-fluctuations that move learners to bifurcations and therefore, direct them toward the appropriate attractors' spectrum that can lead to order in this case, on the condition that the self-organization plays a key role. In fact, on the basis of various impacts (fluctuations), they master the non-linear situation, which leads to the optimization of their intellectual development.

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