Methodic quest: Reinventing the system

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S O Semerikov[1,2,3], I O Teplytskyi[1], V N Soloviev[1], V A Hamaniuk[1], N S Ponomareva[4,1], O H Kolgatin[5], L S Kolgatina[4], T V Byelyavtseva[4], S M Amelina[6] and R O Tarasenko[6]

[1] Kryvyi Rih State Pedagogical University, 54 Gagarin Ave., Kryvyi Rih, 50086, Ukraine
[2] Kryvyi Rih National University, 11 Vitalii Matusevych St., Kryvyi Rih, 50027, Ukraine
[3] Institute of Information Technologies and Learning Tools of NAES of Ukraine, 9 M. Berlynskoho Str., Kyiv, 04060, Ukraine
[4] H. S. Skovoroda Kharkiv National Pedagogical University, 2 Valentynivska Str, Kharkiv, 61168, Ukraine
[5] Simon Kuznets Kharkiv National University of Economics, 9A Nauky Ave, Kharkiv, 61166, Ukraine
[6] National University of Life and Environmental Sciences of Ukraine, 15 Heroiv Oborony Str., Kyiv, 03041, Ukraine

E-mail: semerikov@gmail.com

Abstract. This article is an attempt to rethink the concepts of "methodic" and "methodologic / methodical system" as basic to educational technology. What should be the structure of a methodical system? What is primary – the methodical system or the methodology? How are methodical systems created and developed? How do educational technology and a methodical system relate? How does changing the components of a system make it emergent? These and other issues are explored through the development of a new class of teaching methods – computer-based training systems.

Essentially, all models are wrong, but some are useful [6]
George E. P. Box (1919 – 2013)

1. Instead of introduction: What is method?

A quest is a journey to complete a specific mission or achieve a goal. In literary works, the quest is most often used to show the development of the protagonist – he changes himself and changes others. Vladimir Ia. Propp points out that in all such tales (or, more correctly, tales of quests) there is a common structure of about 150 steps ([25], p. 134).

The protagonist of our quest will be the "method", or rather the "Method of Teaching" and its journey between the science of learning and the art of teaching [33]. As noted by Beatrice H. Barrett in the preface to the 2003 reprint of the paper by B. F. Skinner, "It represented the first attempt to apply a scientifically validated conceptual methodologic system to classroom instruction. ... His methods form a fundamental component in the mosaic of success fulprocedures which, when combined by those fluent in experimental and conceptual ... analysis, produces more dramatic gains than ever before documented – at all education levels" ([34], p. 11).

The Grand Explanatory Dictionary of the Ukrainian Language defines *methodic* as: a) a set of interrelated methods and techniques for carrying out any work; b) a document that describes a sequence of methods, rules and tools for carrying out work; c) the teaching of a particular science, subject matter ([8], p. 664). The first interpretation of methodic is the most general, the second reflects the level of its formalisation in written methodic, and the third specifies written methodic related to the teaching of a particular science or subject. Thus, the teaching methodic of informatics, mathematics, economics, history, German, etc. is a particular (specified at science and subject level) written methodic.

The auxiliary concepts are:

– *mode* – a) a particular action, technique or system of techniques that enables something to be done, accomplished, achieved; b) something that serves as a tool, means, etc., in an action ([8], p. 1375);

– *technique* – a way of doing or carrying out something; a method of researching, studying something ([8], p. 1117);

– *method* – a technique or system of techniques used in an area of activity ([8], p. 664);

– *rule* – a) a regulation that conveys a regularity, a constant relationship of certain phenomena; b) a principle that guides; c) a collection of regulations that define the conduct or observance of something ([8], p. 1100);

– *means/tools* – a) a special action that makes it possible to do something, to achieve something; b) something that serves as a tool in any action, cause; mechanisms, devices, etc., needed to do something, for any activity ([8], p. 420).

The synonymy of some of the above concepts is related to their dual interpretation:

– the mode can be as a system of action or as a means of action, mental or material,

– the technique combines a mode and a method of research,

– method is equivalent to technique,

– the rule is both a principle and part of the methodic,

– the means is equivalent in content to the method.

In order to avoid undesirable duplication, we will assume that the leading concepts of methodic are the interrelated concepts of “means” (mode or tool of activity, mental or material) and “method”, while the auxiliary concept is “principle”. For each particular teaching methodic, these concepts should be made more specific.

The essential characteristic of a methodic is the interrelation of means and methods, which, for a written methodic, should be defined in a specific order of their application to carry out the work – the algorithm for achieving the goal. This makes it possible to identify additional components of the methodic that reflect the described content of the activity, its purpose and result, and also raises the question of the existence of links between them and the interrelated means and methods.

For teaching methods, the activity content is the content reflecting the core activity – the learning content. Learning outcomes can be formalised in different ways – e.g., in terms of competencies.

The Grand Explanatory Dictionary of the Ukrainian Language defines order, due to the correct, orderly arrangement and interconnectedness of something, as a system ([8], p. 1320). However, a system is also: a) a form of organisation, a structure of something; b) a set of elements, units, parts united by a common feature, or purpose; c) a set of principles that form the basis of a certain doctrine; a set of modes, methods, techniques for implementing something; d) a composition, a structure that constitutes a unity of regularly arranged and functioning parts.

Thus, a methodic is by definition a system, so we can talk about methodical systems in general and methodical training systems in particular, about the methodical training systems of a particular academic course.

2. Modelling teaching systems: from hierarchy to multidimensionality

The *traditional methodical system* of teaching is defined by Yurii V. Tryus as a set of interrelated components: learning objectives, content, methods, tools and forms of learning organisation, which create a unified holistic functional structure oriented towards the achievement of learning objectives [41].

According to Anatolii M. Pyshkalo [26], the objectives, content and educational process (methods, tools and forms of organisation of learning) together form a methodical training system, which can be represented as a linear hierarchical structure (figure 1).

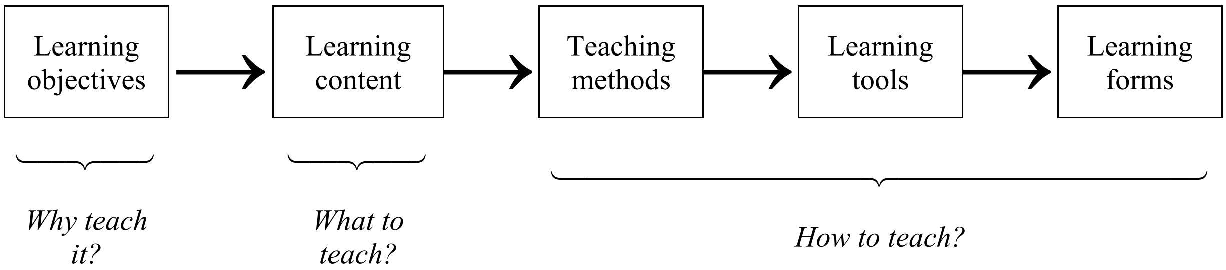

Figure 1. A hierarchical model of a methodical training system.

The hierarchical model does not reflect the inherent relationship between methods and tools, but can be seen as an option for subordinating the components of a methodic (ordering by importance). According to the hierarchical model:

– the learning objectives determine the content, which can be varied because the same objectives can be achieved by mastering different learning content,

– an analysis of learning content enables the best combination of teaching methods to be chosen,

– the effective implementation of a particular teaching method takes place in certain forms of organisation of the learning process,

– the methods and forms of organisation used determine the use of appropriate learning tools.

The problems of the hierarchical model are most significant in informatics teaching, where computer-based learning tools are often the object of study, the mastering of which determines the appropriate learning objectives. Therefore, at the present stage of development of the education system and its informatization, the hierarchical model of the teaching methodical system is no longer adequate to the situation in teaching not only informatics, but also other courses, and needs to be developed accordingly ([19], p. 184).

Yurii V. Tryus defines *computer-oriented methodical training system* as a methodical system of training which provides a purposeful process of acquiring knowledge, gaining abilities and skills, mastering ways of cognitive activity by a subject and developing his creative abilities through extensive use of information and communication technologies [41], which involves changes in both individual components of the methodical training system and the nature of links between them.

Alexander A. Kuznetsov and Tatiana N. Suvorova emphasises that significant changes in educational outcomes are only possible with the transition to a modern information and education environment, and only in such an environment will the use of innovative forms of organisation, new methods and corresponding learning tools, which meet the needs of the subjects of the environment, enable a significant impact on the achievement of educational outcomes ([19], p. 186).

Tatiana Yu. Kitaevskaya notes that at the present stage education is transformed from a means of mastering ready-to-use generally accepted knowledge into a means of information exchange of a personality with the surrounding world, and the educational environment is transformed into a multi-component information and educational environment. In this connection, the methodical training system is becoming an open system under the conditions of wide informatization of society. Thus, it is advisable to consider the structure and functioning of an informatics teaching system from the perspective of a *system approach*, in particular, the theory of dynamic open systems, the main features of which include the following two main factors:

1) the presence of bifurcation points, i.e. unstable positions from which the development of the system can, with equal probability, follow one of the possible alternatives,

2) the existence of attractors – stable dynamic structures that emerge during the development of the system ([16], p. 296).

There should be a *dynamic balance* between all components of the methodical system – a system state characterised by: a) optimal content of the methodical system components: goals, methods, tools and forms of learning organisation; b) potential opportunities for their change under the influence of external information and educational environment; c) striving of the methodical system to find the optimal balancing state and to stay in it by using both traditional and new methodical resources ([16], p. 297).

Tatiana Yu. Kitaevskaya understands the development of the methodical training system as a transition to a new qualitative level based on advanced informatization tools and information technologies, aimed at achieving the predictable result. "The development of a methodical system for teaching informatics in higher education institutions based on the model of an integral system of the educational process, which ensures the organisation, management and orderliness of all elements, as well as its improvement, is a natural step in the development of the education system" ([16], p. 296). System stability is interpreted by the author as a state of sustainable movement, development of the system due to the interaction of system components as well as the interaction of the system with the external information environment ([16], p. 297). In accordance with the general principles of effective functioning of the system, which include *the integrity of the system* (a high degree of interconnection of all its components), *strengthening the integrity of the system* (constant strengthening of the durability of the links between its components), *compatibility of the system with the conditions of functioning* (ensuring compliance of the internal organization of the system and external conditions of its functioning with objective system needs, necessary for its existence and development as an organic integrity), *optimisation of the system* (ensuring a high degree of compliance of the system components with the objectives for which it was created), Tatiana Yu. Kitaevskaya proposes the following principles as the basis for the methodic system of teaching informatics, which ensure the effectiveness of the system:

– focusing on the final goals of informatics training in higher education institutions,

– structuring the informatics teaching process as a goal-oriented programme,

– aiming to achieve harmonious interaction between all elements of the informatics methodical training system, both within a single course and over the whole period of study of the informatics cycle courses,

– correspondence of the methodical system for teaching informatics in higher education institutions to the changing conditions of its functioning (ideology of higher education development, structure and organisational forms of higher education institutions, general trends of scientific development, regional and university peculiarities, etc.) ([16], p. 296).

Sergei V. Shcherbatykh supplements them with the principles of:

– the comprehensiveness of the five components of the methodical system and the coherence of its components (objectives, content, forms, methods and learning tools),

– universality: the designed methodical training system should fit into any individual methodical system, developing and improving it rather than destroying it,

– extensibility: revealing material that is important for future careers by superimposing it on the core content,

– invariance and variation: identifying, selecting and constructing invariant forms, methods and tools that are necessary to achieve the learning objectives,

– predictability: anticipating learning outcomes through a professional application orientation in order to make the necessary adjustments to the content and learning process to achieve the expected outcome ([32], p. 19-20).

Nataliia A. Burmistrova adds the principles of professionally directed teaching:

– continuity: the professional orientation of learning should be realised through all forms of organisation and teaching methods, forming the cognitive motivation of students,

– contextuality: defines the orientation of education towards a professional context, which implies considering the content of subject (e.g. informatics) training as a subsystem of professional education content and makes it possible to identify professionally relevant topics and rationally allocate time for studying theoretical and applied sections,

– integrativity: reveals the interdisciplinary integrative nature of mathematics training and is manifested in the links between the courses implemented by means of mathematical modelling and computer technologies, taking into account orientation and vocational education,

– priority for creative activities: aimed at enabling students to gain experience of creative activities in order to develop the ability to adapt to non-standard life and professional situations ([7], p. 19).

Yurii V. Tryus identified the main conceptual statements for the creation and implementation of computer-oriented methodical training systems [41]:

1) constructing on the principles of:

– gradual and non-antagonistic incorporation of information and communication technologies into existing didactic systems,

– a harmonious combination of traditional and computer-based learning technologies,

– the continuity of pedagogical achievements (classical and new promising), not contesting or rejecting past experience, but on the contrary, improving and strengthening it, including through the use of advances in computer and communication technology development;

2) taking into account of:

– the main principles and main trends in the development of higher education in the world at the beginning of the twenty-first century,

– the main ways to reform the higher education system in order to overcome its most characteristic shortcomings,

– the basic principles for building forward-looking higher education systems,

– the basic principles of higher education development in Ukraine;

4) based on contemporary concepts, approaches and principles of higher education pedagogy and psychology, such as:

– the concept of integrity of the learning and upbringing process of a higher education institution,

– the concept of enhancing students' learning and research activities,

– the concept of flexible pedagogical technology,

– systemic, structural and integrated approaches,

– activity-based, developmental (creative) and subjective-subjective approaches,

– a differentiated and individualised approach,

– person-centred and competence-based approaches.

The design of computer-oriented training systems should be based on the basic principles, patterns and approaches used in designing and creating methodical training systems.

The openness of a methodical training system immersed in a multi-component information and education environment is manifested through the internal dynamics of its elements: objectives, content, methods, tools and forms of learning organisation, as well as the links between them. The methodical system of informatics teaching should be considered in dynamics, and its design should include the analysis and correction of components and links between them, as one of the necessary stages of the technological chain of construction, ensuring the productive functioning of the system; take into account the interaction of the system with the environment; its changes over time, the possibility of evolution ([16], p. 297).

Tatiana Yu. Kitaevskaya believes that the ways for improvement in the methodical system of informatics teaching include:

– the model for a methodical system for teaching informatics is based on the fact that it is, on the one hand, a complex system and, on the other hand, an integral part of the informatization of education,

– structural and functional changes to the components of the system should be aimed at the technologization of the learning process,

– the components of the system are modelled on the principle of differentiation,

– the system model takes into account the need to move towards new principles and technologies of content selection, allowing for constant modification and flexible structuring with a view to selecting individual learning paths,

– the system components are designed taking into account the main factors affecting their dynamics ([16], p. 298).

The process of improving a methodical system of teaching a particular subject follows the below regularities:

1. Changing one or more of the components of a methodical training system involves changing other components and possibly the whole methodical system ([18], p. 17). Thus, a change in objectives entails a change in content, which in turn leads to a change in the methods, means and forms of teaching the course, and consequently in the links between them. At the same time, it is important that the constructed system is *structurally stable*, i.e. that small changes in its components do not affect the performance of the system as a whole: "the isolated design of individual components of a methodical system can lead not only to structural instability of the system, but even to a breakdown of its integrity and thus to the destruction of the system" ([16], p. 297). Thus, the design of an open methodical system aimed at a coherent change in the main components of the system should be based on the principles of dynamic balance, structural stability of the system and feedback.

2. Any methodical training system is inextricably linked to reality, which has a decisive influence on it. The main teaching objectives of a methodical system are the learning objectives in which society shapes the social order for the education system ([18], p. 17). The ability to adapt to rapidly changing external conditions (adaptability) is one of the necessary properties of a methodical system ([16], p. 297).

Oleg A. Kozlov believes that it is advisable to base the formation of training objectives in general and, in particular, of basic informatics training on the activity-based approach: "it makes it possible to construct an invariant information component of the model ... of a specialist in the form of a fragment of a qualification characteristic" ([18], p. 32). Thus, defining training objectives in terms of a specialist model – in particular his/her professional competencies – corresponds to the application of an *activity-based* and *competence-based approach* to specialist training. The approach proposed by Oleg A. Kozlov, which ensures that the learning objectives are reflected in the content of the basic informatics course, is based on a parallel specification of learning objectives and content, which uses *the modular principle* of building the content of the course ([18], p. 32).

Nataliia A. Burmistrova points out that when applying the "competence-based approach there is a need to change ... learning objectives ... in connection with the transition ... to integrative learning outcomes, ... which, in turn, ... provides for the implementation of technological approach to learning, which highlights as one of the requirements to the formulation of objectives its diagnosticity (objectives should reflect the projected learning outcomes). In the logic of competence approach the goal of learning ..., consisting in the construction of students ... knowledge, skills, abilities, personal qualities included in the content of general cultural and professional competences" ([7], pp. 18-19), individual experiences of which form the basis of the informatics competencies of future mathematics teachers.

Aleksandra A. Tolsteneva divides learning objectives into educational (improving students' level of education), upbringing (forming professional orientation of personality and value attitude to the study of the course) and developing (formation of informational mobility) ([39], p. 24).

The main *objectives of informatics teaching* in higher education institutions are dictated by the social and economic needs of society, the level of technological development, the trends in the development of the methodical system of teaching the subject, the prospects for the development of the higher education system and are formulated through the social order for training specialists ([16], p. 296). The transformation of learning objectives begins with changing the starting points of their genesis and establishing a link to the predicted learning outcomes. Defining objectives then requires not only an analysis of relevant educational development documents (indicating social demand on the level and nature of education), but also a description in terms of measurability and diagnosability ([19], p. 185). Thus, the projected methodology defines levels of informatics competencies and diagnostic tools – matrices describing each competency component at the corresponding level.

The learning content is changing to take account of prospective developments in technologies in order to provide advanced training with the extensive use of e-learning resources. Liudmila L. Bosova defines the following set of requirements for selecting and structuring informatics learning content: coherence (the learning content of a particular informatics course should be interlinked with others), continuity (all informatics courses should have cross-curricular content lines), meta-disciplinary focus (learning content should be selected to ensure the development of both key and professional competences), taking into account the needs of the subject of learning for self-realisation and self-development, and the foundation of learning content on the basis of a didactic spiral ([5], pp. 27-28).

The main changes regarding *learning forms* are related to the gradual loss of importance and absolute priority of the classroom-based (lecture and class) system over other forms, in particular individual learning. The current level of ICT development makes it possible to create electronic educational resources for adaptive learning, in which in the process of modelling the learner (student) is individualized learning by taking into account his or her diagnosed individual characteristics in achieving learning objectives. In addition, modern ICT tools make it possible to apply such forms of learning organisation as video lecture, webinar, remote consultation, etc. ([19], p. 185).

Teaching methods change considerably: traditional methods are being implemented in new contexts, e.g. illustrative method is actively supported by demonstration software and information retrieval systems; project method, which started long before the development of modern technologies, is now implemented through a wide range of software tools. Moreover, the implementation of ICTs has brought to life a number of new teaching methods (training computer modelling, falsification method, precedent method, associative method, etc.). ([19], p. 185).

Traditionally, *learning tools* have been clearly defined by teaching methods, but as learning tools have become much more capable, the situation has changed and they have a much higher degree of influence on computer-oriented teaching methods, which are more characterised by a flexible system in which formerly lower hierarchical elements begin to influence higher ones and even change their position in the system. This trend is particularly evident in the increasing role of e-learning resources as learning tools that are beginning to largely shape technology components (learning forms and teaching methods) and learning content ([19], p. 185).

Alexander A. Kuznetsov proposes a two-level model of a computer-oriented methodical training system in which the learning objectives are the determining ones (figure 2). However, in modern conditions, the components of the methodical system are in a specific relationship, far from top-down hierarchical subordination, and mutually influence each other, as reflected in Illia O. Teplytskyi's model (figure 3).

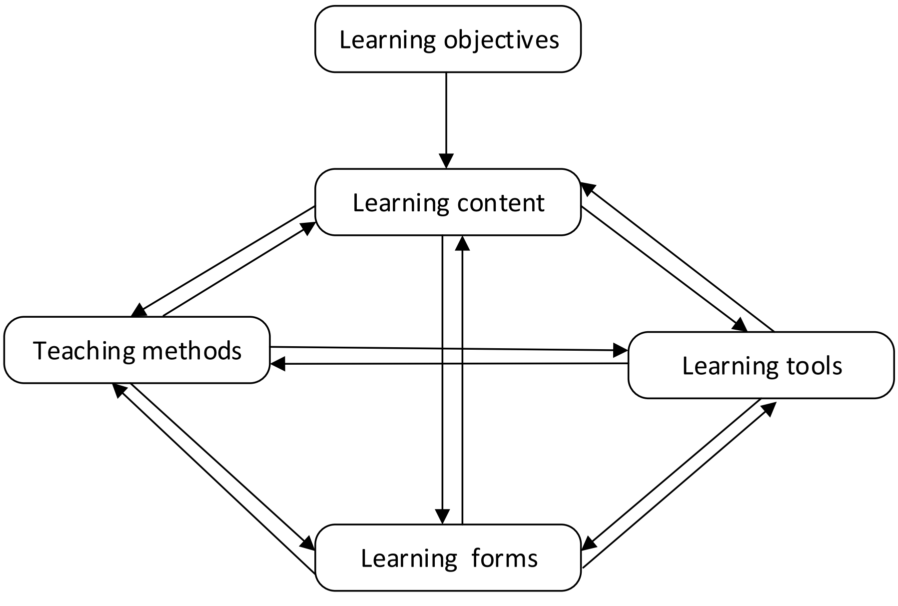

Figure 2. Links between the elements of a methodical training system in an informal learning context (model by Alexander A. Kuznetsov ([19], p. 186)).

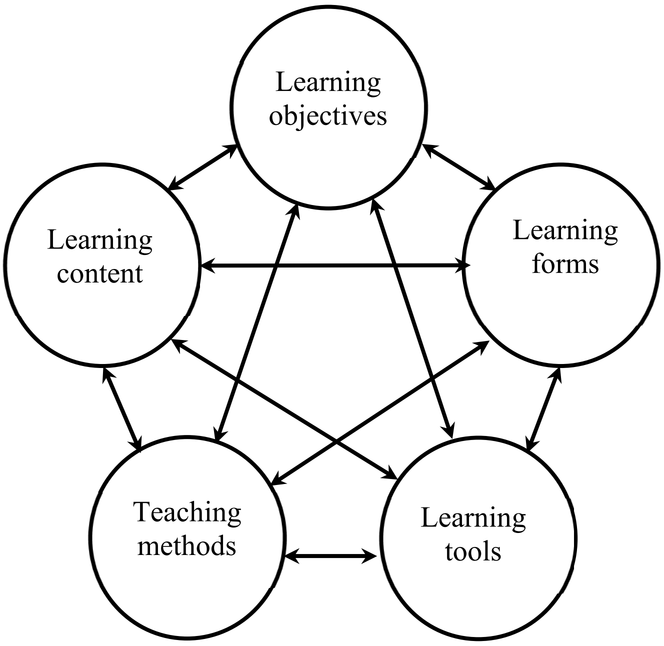

Figure 3. A full-linked five-component model of a methodical training system (by Illia O. Teplytskyi ([36], p. 90)).

Nataliia A. Burmistrova proposes a similar model, consisting of purposive (learning objectives), organisational (learning forms), procedural (teaching methods and learning tools) and content (learning content) components linked through learning outcomes (figure 4). The model by Nataliia A. Burmistrova, unlike the model by Illia O. Teplytskyi, attempts to technologize the methodical training system, but the proposed structure violates the interconnectedness of the main components of the model: some of them are connected directly and some are connected only through learning outcomes.

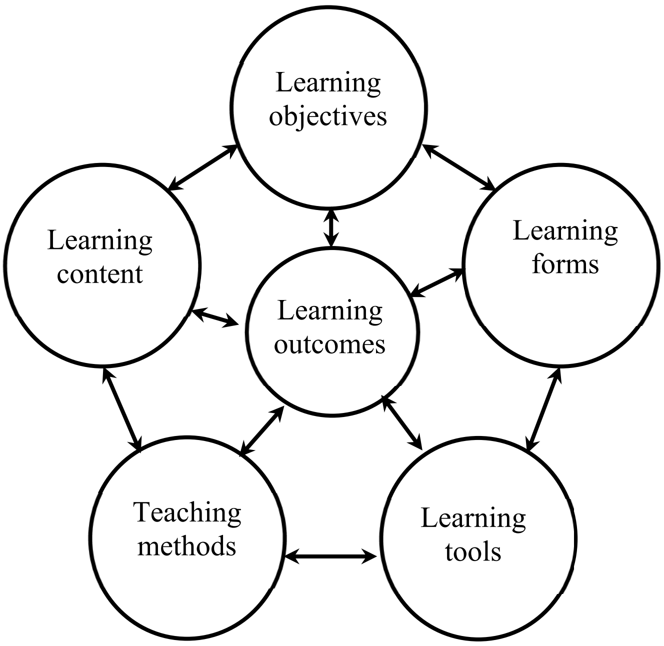

Figure 4. The five-component model of the methodical training system, supplemented by learning outcomes (according to Nataliia A. Burmistrova ([7], p. 20)).

A more reasonable approach to the technologization of the methodical system is suggested by Larysa O. Chernykh, who, considering the totality of those components of the traditional methodical system that answer the question “how to teach”, believes that they form some subsystem of a unified system: “We will call *teaching technology* a subsystem of the methodical system that includes methods, tools and learning forms and should answer the question ‘How to teach?’” ([10], p. 18). A schematic representation of the methodical system structure with a dedicated technological subsystem is shown in figure 5.

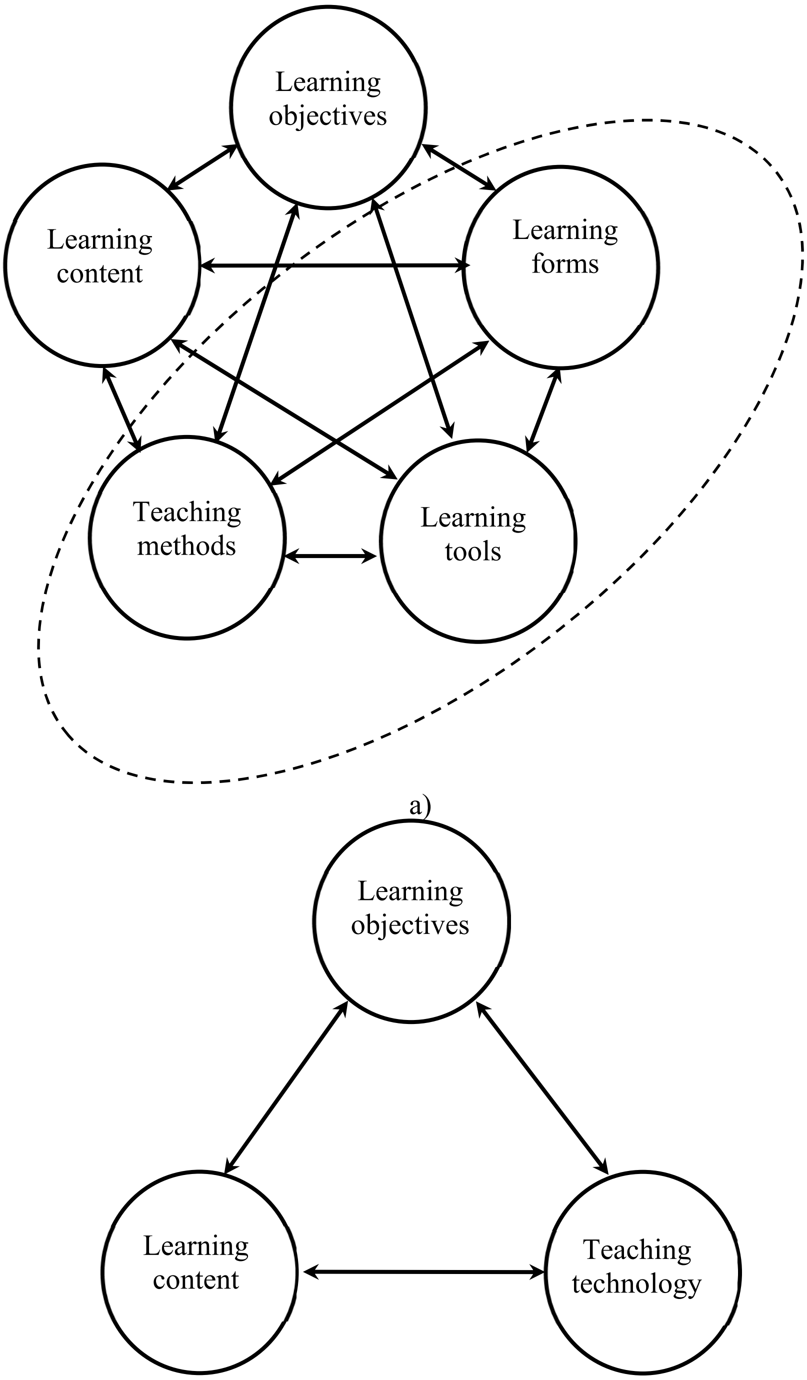

Figure 5. The structure of a methodical system with a distinguished subsystem of "teaching technology" (according to Larysa O. Chernykh ([10], p. 18)).

Margarita A. Ariian suggests a hierarchical multilevel model with feedbacks: 1) the level of the system, combining the needs of society at large and the individual, 2) the level of objectives, 3) the level of teaching approaches and principles, 4) the level of subjects of the pedagogical process, combined with learning content, 5) the level of organizational and pedagogical conditions of education, 6) the level of outcome ([2], p. 30).

Irina B. Mylova's leading idea for building a methodical system is the definition of a planned result through professional information-technological competence of a teacher, the implementation of which is proposed through the integration of information technology education with professional teacher training ([22], p. 24). Accordingly, the author's model consists of the regulatory elements which influence the interrelated process elements and learning outcomes. Figure 6 presents a generalised scheme of the links between the elements of the methodical system. Irina B. Mylova's model does not explicitly contain learning objectives – it is the second level of Alexander A. Kuznetsov's model, interlinked with learning outcomes.

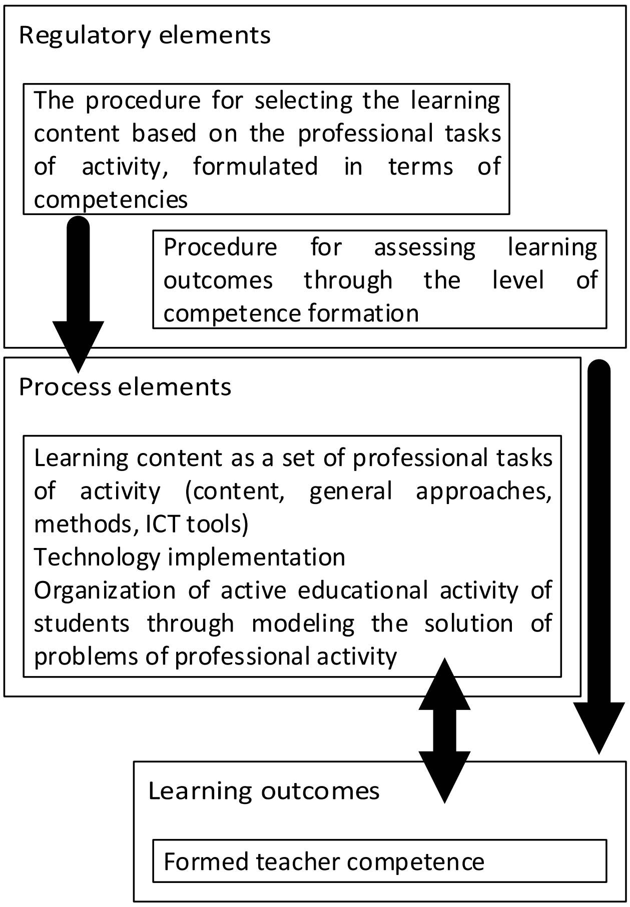

Figure 6. The links between the elements of the methodical system of teaching information technologies (interpretation of Irina B. Mylova's model).

Aleksandra A. Tolsteneva incorporates the following general principles into the methodical training system: scholarship; consistency; systematicity and consistency; unity and optimum combination of collective, group and individual learning forms; optimum combination of verbal, visual and practical methods; solidity of knowledge; differentiation; interdisciplinary integration; principles of content selection and structuring ([39], p. 18).

Maria A. Urban suggests the following components as part of a methodical training system ([43], p. 8):

– purposeful (a learning objective that has a knowledge-based, activity-based, competence-based and personality-based component),

– content (list of skills),

– procedural (methodic for forming the necessary skills through a set of tasks, the techniques included in the methods and the corresponding skills, the forms of interaction between the subjects), highlighted in terms of the combination of visual and practical verbal methods,

– control (criteria for evaluating the effectiveness of the methodical system – learning ability in the subject area, competence, motivation to learn).

Figure 7 shows the model developed by Maria A. Urban for a methodical system of elementary mathematics teaching using educational modelling ([43], p. 18). In contrast to Alexander A. Kuznetsov's two-level model, Maria A. Urban's model contains feedback of the objective component with all other components. At the same time: the content component of the model includes both learning content and requirements for training subjects; the objective component is formulated in terms of competencies; the control component provides multilevel diagnostics – input control, current monitoring and control of learning achievements, as well as evaluation of the effectiveness of the system as a whole; the process component does not include learning tools separately in explicit form, but includes all technological components within the method of modelling skills formation.

Marina V. Egupova proposes a similar model of methodical system, including objective, content, methodical (instrumental) and results-evaluation components ([11], pp. 30-31). Additionally, the model contains learning levels and the specification of content modules, and the learning objectives are defined by the competencies to be formed by the future mathematics teacher and concretised in the learning content.

Tatiana Yu. Kitaevskaya identifies the following main structural components of a methodical training system (figure 8): goals and planned learning outcomes, learning content, subjects of learning, as well as information design technology for differentiated learning content as the main integrating component of the system, which structures the tasks of teaching the subject (methodical task) teaching methods, learning tools, learning forms, technology selection, which structure the technology to solve the methodical task (informatics teaching technology), the result of the functioning of the methodical system (evaluation and outcome component). The basis for linking the elements of the system is the learning objectives of the subject and the informatics learning process itself ([16], p. 299).

The development of methodical training system occurs under the influence of external factors affecting the development of methodical system in general, as well as its individual components ([48], p. 12), therefore, the model of methodical informatics training system proposed by Tatiana Yu. Kitaevskaya's takes into account specific non-hierarchical relations between the system components: teaching objectives, which are a higher degree of abstraction than other elements of the methodical system, turn from a leading system element into a subordinate one and are gradually adjusted along with the teaching content. At the same time, in spite of the declared connection of the methodical system of informatics teaching with the corresponding information and educational environment, this model lacks the essential for such an environment direct links between the learning subjects. In addition, the diagnostic and monitoring tools for learning outcomes do not have an operational feedback with the technological component of the methodical training system.

Aleksandra A. Tolsteneva includes independent work of students as a separate component of the methodical training system, interconnected with the methods and forms of learning organisation ([39], p. 21). The conditions that make it possible to organise students' independent work effectively include the creation of new types of textbooks and teaching guides, the implementation of new forms of learning organisation, work to improve teachers' psychological and pedagogical qualifications and skills, etc. ([16], p. 296).

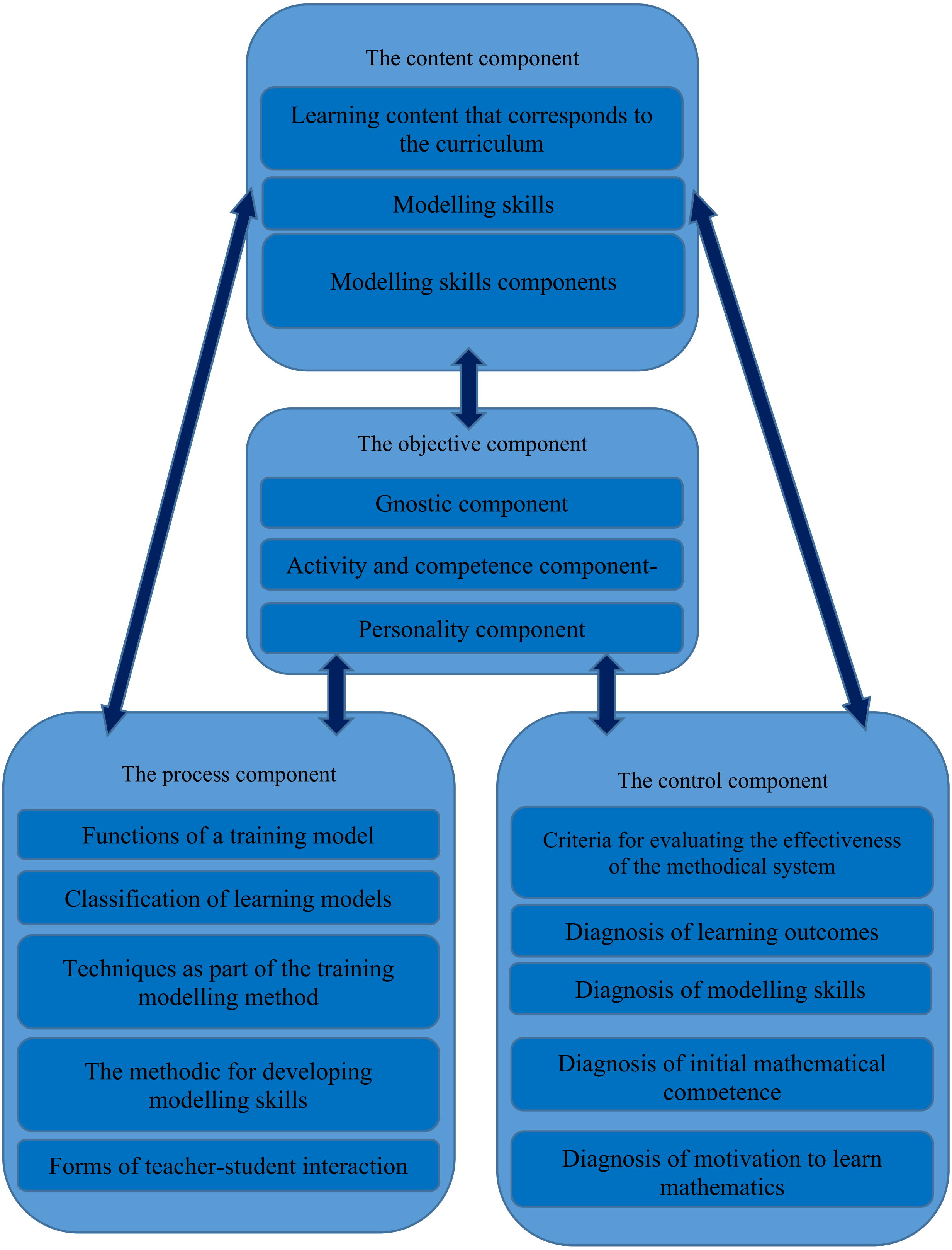

Figure 7. The structure of a methodical system of elementary mathematics teaching using educational modelling (by Maria A. Urban ([43], p. 18)).

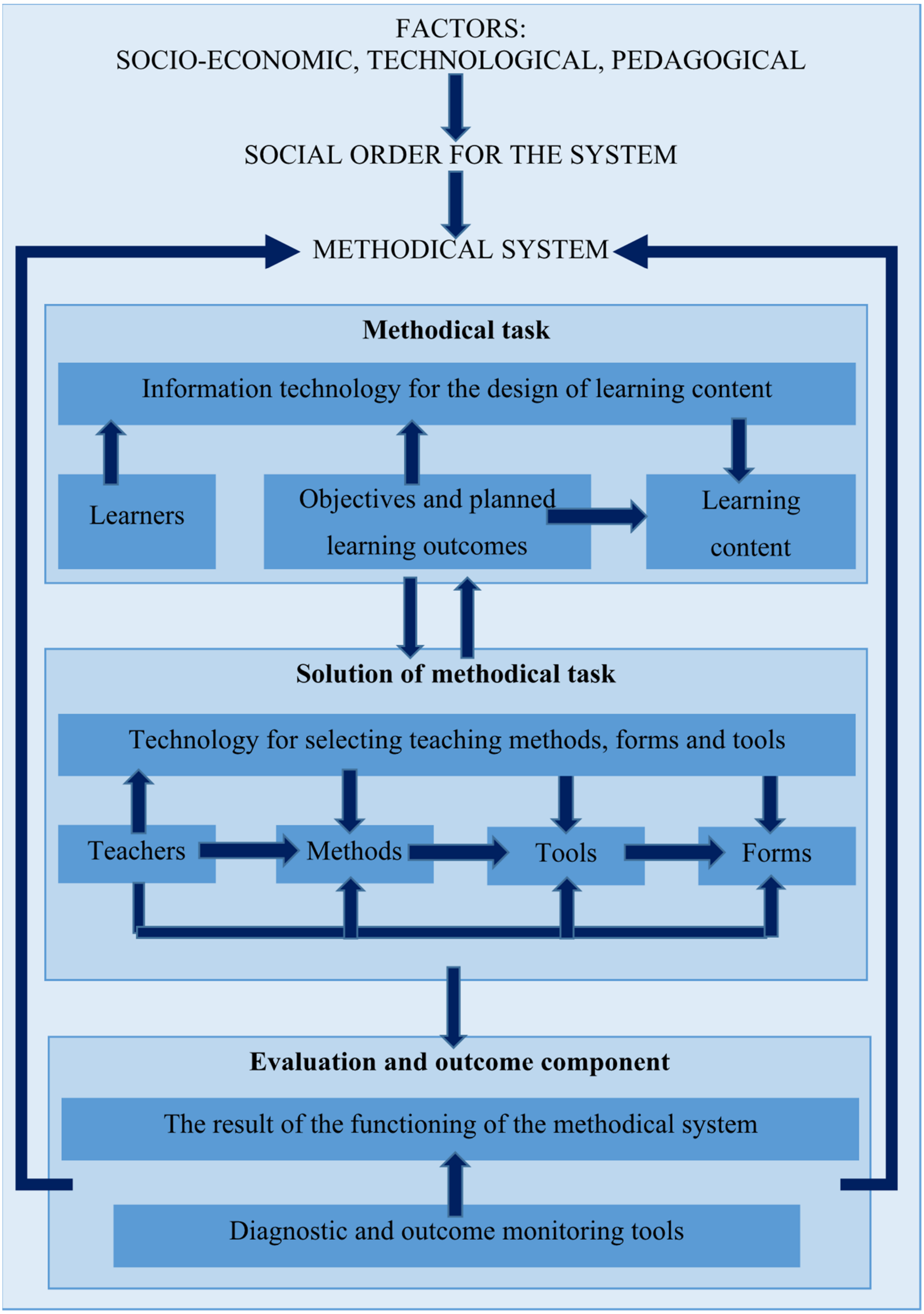

Figure 8. Model of a methodical informatics training system with highlighted external influencing factors (by Tatiana Yu. Kitaevskaya ([16], p. 299)).

Iurii B. Altshuler understands methodical training system as a complex of interrelated structural (reflecting objectives, methods, forms and learning tools, modular structure of the section and content of learning material) and functional (reflecting learning and cognitive activity of the student and developing, diagnostic and controlling activity of the teacher to achieve the objectives) components ([1], p. 23). The model of methodical training system he proposes consists of the following components: motivational and objective, structural and content, procedural and activity-based (including independent work) and evaluative and results-based ([1], p. 21). Iurii B. Altshuler links the first component with the social order through state educational standards, approaches (competence-based, activity-based, systemic, and integrative) and principles (in particular, cyclicality, generalization, modularity). The author specifies the result through the desired level of a certain competence. Unlike Tatiana Yu. Kitaevskaya's model, Iurii B. Altshuler's model provides for a possibility of returning to any of its levels ([1], p. 22), which corresponds to Winston Walker Royce's cascade model structuring [28].

Vita I. Glizburg in the model of methodical system of teaching topology and differential geometry of the future teacher of mathematics in the aspect of humanitarianization of continuous mathematical education ([13], p. 28), in contrast to the model of Tatiana Yu. Kitaevskaya, considers both direct connection of learning subjects (teachers and students), and indirect technology (methods, tools and forms of organization of learning).

Thus, in the process of its journey between the science of education and the art of teaching, our teaching method has found companions and formed a team with them – a methodical system, whose further expansion and advancement in the forest of teaching practice has necessitated taking into account numerous external influences and internal restructuring; the appearing of sub-systems capable of self-development. What is the composition of this methodical troop?

3. Example: A model for a computer-oriented methodic for training prospective mathematics teachers in informatics

Let us try to concretise what the development of modern teaching methodic looks like with the example of informatics education for prospective teachers of mathematics. Why did we choose them in particular?

1. The State National Programme "Education" ("Ukraine of the XXI century") among the priority areas of education reform determines, in particular, the achievement of a qualitatively new level in the study of mathematics through the optimal combination of humanitarian and natural and mathematical components of education and wide use of new educational, information technologies through appropriate teaching, methodical and information support [9], and The Presidential Decree on declaring the academic year 2020/2021 the Year of Mathematics Education in Ukraine provides for the creation of conditions for equal access to modern and quality mathematics education and for ensuring a modern level of mathematics teaching, in particular through the use of effective technologies, taking into account the best national and international practices [24].

2. Analysis of the current state and prospects of development of information society in Ukraine and the world (Klaus Shwab and Nicholas Davis [29]), the potential of information technology as a means of integrating mathematics, computer science and natural sciences (Mikhael Gromov [14], Vladimir V. Laptev, Natalia I. Ryzhova and Mikhail V. Shvetckii [20], Aleksei L. Semenov [30],), as well as problems of informatics training of future mathematics teachers (Andrey P. Ershov [12], Vladimir M. Tikhomirov [38], Myroslav I. Zhaldak [46]) discovered, that the prospects of development of digitalization means should be reflected in the advanced content of informatics disciplines at all levels of education, therefore special attention requires modernization of information training and an appropriate system of informatics competences of prospective teachers (Yurii S. Ramskyi [27], Viktoriia M. Zhukova [47]), since the teacher is responsible for introducing ICTs directly into the learning process, shaping the informatics competencies of students, and preparing a new generation to live fully in an information society.

3. Mathematics and informatics are related sciences that significantly influence each other in their development and largely determine the development of natural sciences and technologies. The main source of change in the education system is social demand, reflecting the development of technologies, science and socio-economic relations. In the 20s of the 21st century this complex, called Industry 4.0, is extremely informatized, which necessitates refining the informatics competencies of prospective teachers by reflecting new content and new abilities in them. The development of core and subject-specific ICT (digital) and mathematical competencies in the European educational space is seen as a component of the fundamental literacy of employees demanded in the labour market of the future [37]. Therefore, in the process of developing general professional digital competencies of a teacher, the following important ICT innovations, such as open educational resources, social networks, mobile technologies, Internet of Things, artificial intelligence, virtual and augmented reality, big data, programming, ethics and privacy protection, should be considered through the content of the training [42].

Thus, there is a socially conditioned and legally justified need to improve the quality of prospective mathematics teachers' training, in particular – informatics training. One of the leading directions of achieving this goal is the development and implementation of computer-oriented methodical systems and tools for training prospective teachers of mathematics aimed at the formation and development of their informatics competencies.

Through an analysis of French, US and Australian teacher education standards, we have identified components and indicators of general digital competencies such as the ability to: assess, implement and use ICT-based learning platforms; apply e-learning in social media; teacher design for e-learning; assess, implement and evaluate e-assessment; apply ICT-related knowledge; implement enhanced learning practices; analysis of production implementations and e-learning systems. The recommendations of the Association of Mathematics Teacher Educators [3] and the National Council of Teachers of Mathematics [47], aimed at a pedagogically appropriate and balanced use of ICT in mathematics teaching in general secondary education, are particularly noteworthy.

The carried out analysis of models of methodical training systems provided an opportunity to develop a model of computer-oriented methodic for teaching informatics to prospective teachers of mathematics (figure 9). The choice of methodic as a modelling object is related to the need to reflect in the model the structural components of a methodical training system, technologized in terms of competence outcomes and objectives, external factors affecting the system, principles and approaches to its design.

The methodic is computer-based because ICT:

a) define the aim – the formation of informatics competencies of prospective mathematics teachers through external factors: on the one hand, there is a need to change the system of professional informatics competencies to reflect the current and future development of ICT, in particular Industry 4.0 tools, and on the other – the crisis of science and mathematics education in Ukraine and the lack of highly qualified mathematics teachers need to modernise the professional training of mathematics teachers,

b) act as design factors – the system of informatics competencies of future mathematics teachers is projected on the basis of a comprehensive analysis of the sphere of knowledge “Information Technology”, taking into account the professional orientation of informatics teaching courses,

c) are leading teaching tools for information technology courses.

The model reflects the main stages of the process of formation of informatics competencies of a mathematics teacher.

The first stage defines the **aim**: formation of informatics competencies of prospective mathematics teachers, which are an integral part of professional competencies of a mathematics teacher, which are generalized in integral competency: ability to solve complex specialized tasks and practical problems in general secondary education in the process of teaching mathematics, which involves application of psychological and pedagogical theories and teaching methods and is characterized by complexity and uncertainty of conditions. The formulation of the aim is the result of socio-technological factors external to the methodical system and methodic (crisis phenomena in science and mathematics education, public demand for competent teachers, the need to change professional informatics competencies and the new tools of Industry 4.0).

The aim determines the actions to be carried out in the second stage – **systems design**. The choice of the name of the component is connected with the fact that the objective predetermines the necessity of designing the system of informatics competences of a mathematics teacher, while the methodic determines the necessity of designing a computer-oriented methodical system of informatics training of prospective mathematics teachers. The design of the two systems is based on:

a) methodological approaches:

– *the system approach* (based on the idea that the whole surrounding world consists of interconnected and interacting objects that form a dynamic whole that is more important than its parts [35]) applies to design: a) to overcome the complexity of a prospective mathematics teacher's integral competence by breaking it down into its individual components, using abstraction and hierarchies of subordination and emulation, b) for the "theoretical construction of [methodical] system components, its internal and external links, and the subsequent implementation of such an idealised system in the real learning process" ([10], p. 19),

– *the competence-based approach* (based on the idea that knowledge and activities that are personally relevant form more stable structures [45]) is used to structure the content of IT training, formulate learning objectives, define learning outcomes, and monitor and diagnose learning activities,

– *the activity-based approach* (based on the idea that learning activity is a specific form of cognitive activity in which a person achieves consciously set learning objectives, which are formed as a result of self-development needs [31]) is used to design mandatory and variable (learnt independently) components of the system of informatics competencies and technologies to implement students' independent learning activities in a computer-oriented informatics learning environment,

– *a person-centred approach* (based on taking into account the personal qualities, individual needs and capacities of students, and promoting their self-development [15]) is used in the implementation phase to adjust the components of the methodical training system: "the cyclical nature of ... activities at the methodical level involves the repetition of ... cycle [of methodical system development and implementation], but already in conditions of a qualitatively new learning process" ([10], p. 19),

– *structured-modular approach* (based on structuring the educational programme into documented, meaningfully completed, relatively independent parts, characterised by their coordination of objectives, content, methods, tools and learning forms [40]) is used to highlight the components of computer-oriented methodic for teaching informatics to prospective mathematics teachers (specific methods for forming individual groups of informatics competencies),

b) principles:

– *the principle of harmonious combination of traditional and innovative technologies* (based on bringing established and emergent methods, tools and forms of learning organisation into a state of correspondence, coherence in order to increase the effectiveness of the methodical system) is applied when selecting the components of informatics teaching technology,

– *the principle of continuity* (based on the idea that the different stages of development are interlinked, with the essence of the new stage restoring and preserving elements and characteristics of the previous stages [4], in particular – that the development of a methodical training system should be based on an already existing training system ([20], pp. 18-19)) is applied when designing the system of informatics competencies of a mathematics teacher as an improvement of the system by Yurii S. Ramskyi and in the process of developing the methodical training system: each of its new models is based on the previous one,

– *the principles of designing an open methodical system:*

1) *the principle of dynamic balance* (based on the idea that a methodical system finds and maintains an optimal balance through a harmonious combination of traditional and innovative technologies ([16], p. 297)) used to identify the external conditions and internal contradictions that necessitate the development of a methodical training system,

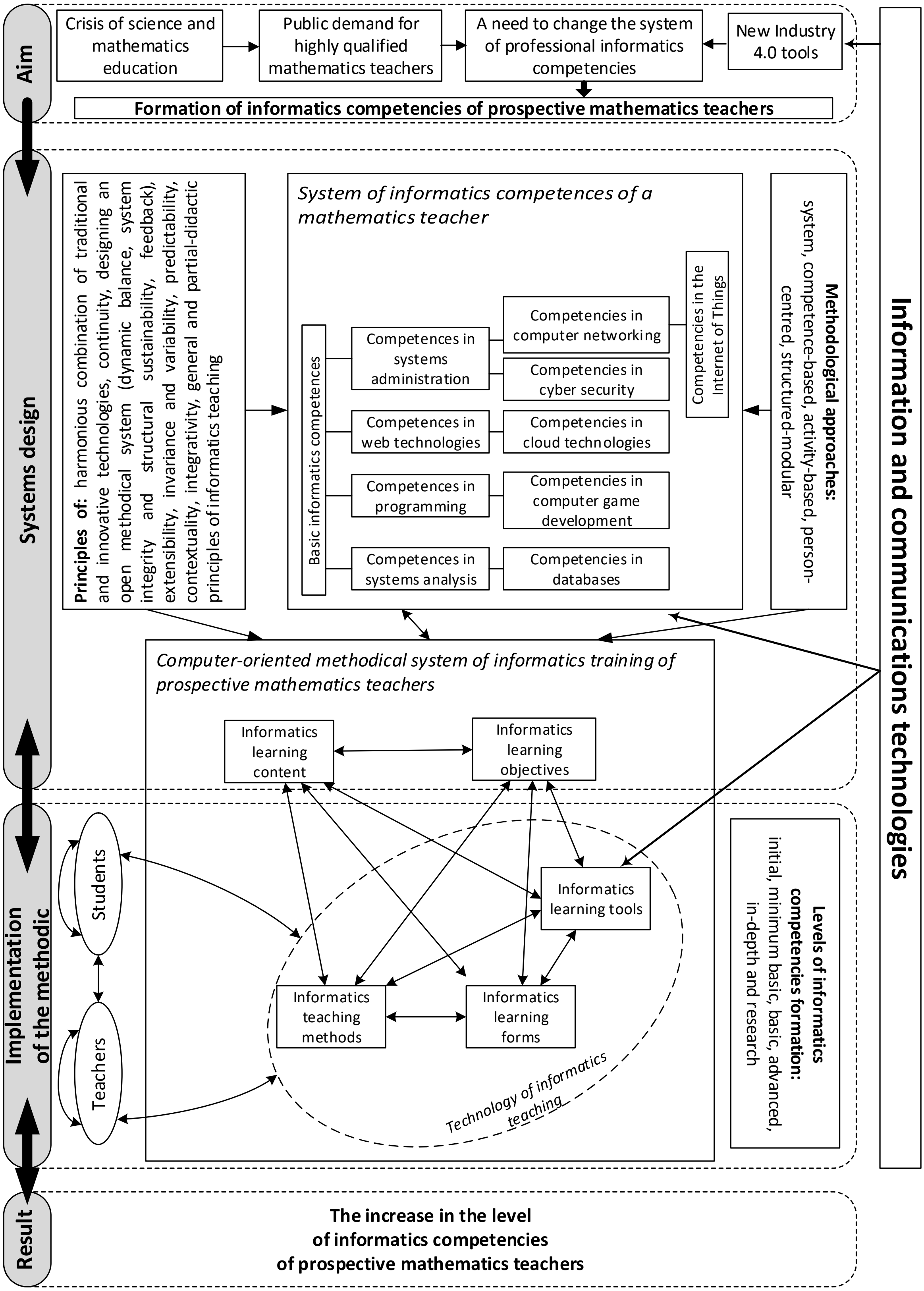

Figure 9. A model of computer-oriented methodic for teaching informatics to prospective mathematics teachers.

2) *the principle of system integrity and structural sustainability* (assumes a high degree of interconnectedness of all system components, whereby a minor change in the components does not affect the performance of the system as a whole ([16], p. 297)) is used to stabilise the methodical training system before a critical mass of changes to the system components has accumulated, prompting a re-design of the system,

3) *the feedback principle* (provides the connection between the output of the system and the input as part of a causal chain) is used to adjust the components of the methodical system when the obtained result (a certain level of formation of informatics competencies) deviates from the desired one (the predicted level of formation of informatics competencies),

– *the principle of extensibility* (based on the idea of gradation of qualification levels, in which the transition to the next level requires a change in knowledge, skills, ways of interaction and the ability to apply them independently and responsibly) is used to specify and specialise informatics competencies corresponding to different levels at system design stage, and to develop a computer-oriented learning environment for information courses at implementation stage,

– *the principle of invariance and variability* (identifying, selecting and constructing invariant forms, methods and learning tools whose use is necessary to achieve the learning objectives) ([32], p. 19-20)) applied in the selection of invariant and variable informatics competencies, as well as in the process of designing informatics learning content (slowly changing fundamental and rapidly changing technological) and combining traditional and innovative components of educational technology,

– *the principle of predictability* (based on the idea of anticipating learning outcomes in order to make the necessary adjustments in content and learning processes to achieve the expected outcome ([32], p. 19-20)) is realised by reformulating the learning outcomes from improving the level of informatics competencies of a mathematics teacher to the level desired in certain specific implementation contexts,

– *the principle of contextuality* (based on the idea of contextual learning, in which all the components of the methodical system, together with the professional and socio-cultural content of the work of prospective specialists, are modelled in their development ([44], p. 266)) is realised in informatics learning technology through professionally oriented learning activities, above all, constructive project-research activities in a computer-oriented learning environment of informatics courses,

– *the principle of integrativity* (based on the idea of interdisciplinary integrative nature of mathematics teacher training and manifested in the links between courses implemented by means of mathematical modelling and computer technologies, taking into account field and vocational education ([7], p. 19)) is applied at the level of learning technology by integrating its components into learning strategies,

– *general didactic principles of informatics teaching* [17]:

1) *the principle of the unity of the educational, developmental and upbringing functions of learning* (applied to learning, which is aimed at achieving the purposes of comprehensive personal development, at shaping his/her competencies and worldview, which are the basis for choosing life ideals and social behaviour) is reflected at the system design level in the components of each competency: knowledge and skills reflect the educational function, attitude – the upbringing function, and at the methodic implementation level – the developmental function through the competence formation process,

2) *the principle of scientific content and teaching methods* (applied in connection with modern scientific knowledge and social practices, according to which the content of teaching should correspond to the current state of science, determine the mastery of methods of scientific knowledge and involve the disclosure of scientific phenomena and facts in relationships and interrelations, the use of problem-based learning and research methods in the organisation of activities) is reflected at design level: The following is reflected: scientific content – in the content of informatics competencies, which was selected in accordance with the current state and future developments in ICTs; scientifically based teaching methods – due to the application of the contextuality principle and the research nature of learning activities in higher education,

3) *the principle of systematicity and consistency* (based on the fact that teaching and learning should be carried out in a logical sequence, according to the system, which ensures the continuity of substantive

and procedural aspects of learning, consolidation of knowledge, skills, personal qualities of the student, their consistent development and improvement, where each lesson is a logical continuation of the previous one both in terms of the content of learning material and the nature and methods of cognitive activity) is reflected in the structural-modular approach and multilevel system of competencies, in which the transition to the next level is possible only after mastering the previous one, and the hierarchical structure of competency system reflects the relationship of concretization and specialization,

4) *the principle of solidity of knowledge* (reflecting the thoroughness of the acquisition of knowledge, skills and abilities, sustainable fixation of the acquired in memory, free reproduction and application of it in practice, where during the preparation for familiarisation with the new material the interests of students are appropriately directed, a positive attitude towards what is being studied is formed, and assimilation of the content should be organized so that students take the most active part in it, in a sufficient number of exercises, with vivid examples, on visual material) is reflected at the design level in the components of each competence as a dynamic combination of knowledge, skills and relations, and at the implementation level – in informatics teaching technology,

5) *the principle of accessibility* (it determines the specificity of students, it is related to the need for teachers to find ways to establish contact with each student, to select such methods and teaching tools that promote optimal learning of educational material in accordance with a particular stage of their mental, moral, social and physical development, in compliance with the following rules: in teaching it is necessary to pass from easy to difficult, from known to new, to unknown; take into account the difference in levels of progress in the learning process of individual students) at the design level is reflected in a personality-centered approach, and at the level of the methodic implementation is considered in the computer-oriented environment of informatics teaching through monitoring and diagnostics of the student component of the environment in order to adjust components of informatics teaching technology to achieve the desired level of informatics competencies formation,

6) *the principle of awareness and activity* (based on the fact that the student is a subject of the learning process, is aware of the learning objectives, is able to plan and organise his/her own work, is aware of the personal importance of its results, and cognitive activity is active for students only when they perform it independently, when it is fundamentally new for the student, when it is organised consciously and purposefully) specifies the main provisions of activity approach at the level of methodical implementation,

7) *the principle of visibility* (based on the fact that the effectiveness of learning depends on the appropriate involvement of human senses in the perception and processing of educational material, and provides for the use in the learning process of various visual tools: natural (objects of objective reality), experimental (experiments), volumetric (models, figures, etc.), visual (paintings, photographs, drawings), sound, symbolic and graphic (maps, graphics, diagrams, formulas), internal (images created by the teacher's speech)) is implemented in the technology of informatics teaching through the use of ICT as a universal learning tool, provides an opportunity to increase its mobility,

8) *the principle of connection between learning and practice* (expresses the need to prepare students to apply knowledge in solving practical problems by analysing situations and examples from real life, familiarity with production, social institutions, involvement in useful activities within and outside the institution of higher education, using the surrounding reality as a source of knowledge and as a field of its practical application) at the system design level concretises the principle of contextuality and the professionally relevant content of informatics learning,

9) *the principle of individualisation* (aimed at taking into account individual characteristics and creating conditions for the development of each student, which requires the teacher to have a clear understanding of the nature, interests and abilities of the student, and the methods, techniques and pace of learning are selected taking into account the differences of students, the development levels of their cognitive abilities) at the level of system design specifies a person-centred approach to learning, and at the level of methodic implementation is considered similar to the principle of accessibility,

– *partial-didactic principles of informatics teaching*, in particular

10) *the basic principle of teaching theoretical informatics*, formulated by its authors as “Theorem + Proof of Theorem + Algorithm + Proof of Algorithm Correctness + Investigation of Algorithm Complexity” ([20], p. 130), is applied in the content of teaching functional programming (λ-calculus and combinatorial calculus), system programming (especially regular expression calculus, calculus of grammars), algorithm theory (Turing machine, etc.) ([20], p. 130).

The system of informatics competencies of a mathematics teacher is designed as a hierarchy, with each level being a certain specialization or concretization of the previous one, which allows considering them as interrelated with the levels of informatics competencies formation – this explains the fact that for certain groups of competencies the indicators of their formation are not defined at all levels. The first level contains the basic informatics competences, which are concretised in the second level into competences in systems administration, web technologies, programming and systems analysis. The third level corresponds to the specialisation of: competencies in systems administration – competencies in computer networking and cyber security; competencies in web technologies – competencies in cloud technologies, competencies in programming – competencies in computer game development; competencies in systems analysis – competencies in databases. The fourth level reflects prospective competencies in the Internet of Things, a further specialisation of competencies in computer networking.

The computer-oriented methodical system of informatics training of prospective mathematics teachers is built according to Larysa O. Chernykh's model. At the level of theoretical design all its interrelated components are defined (objectives, content and technology of informatics teaching represented by tools, methods and forms of its teaching organisation).

Both systems are interlinked not only through learning objectives and technologized outcomes formulated in terms of the informatics competencies of a mathematics teacher, but also through learning content aligned to the content of the informatics competencies.

Table 1. Leading tools for forming informatics competencies

Tools	Competencies
software and hardware testing	in basic system administration and ICT systems support
text editors	in application software, computer network administration and the development of dynamic computer games
database management systems	in application software, databases, dynamic computer game development and ICT system support
communication tools	in serving client requests and organising safe collaboration
digital media tools and tools for creating interactive animations	in digital media, modelling and effects development for computer games
tools for creating and editing digital images	in digital media, web development, modelling and effects development for computer games
project management tools	in programming technology, in design activities, in the design and implementation of quality assurance processes
software development tools	in project activities and in programming technologies
tools for creating documents in the XML markup language	in the use of markup languages and in web programming
SQL relational database access tools	in database and web programming
software testing and deployment tools	in programming technologies and the development of dynamic computer games
mobile software development tools	in the development of mobile applications and dynamic computer games
computer modelling tools	in developing dynamic computer games and models and effects for them

The second stage and **the third, implementation of the methodic**, are interlinked: the implementation of the methodic involves continuous monitoring and control of its performance, the improvement of which may require adjustments to the designed systems. The competence matrices designed at the previous stage act as a comprehensive means of diagnosing the formation of informatics competencies at one of six levels: initial, minimum basic, basic, advanced, in-depth and research. The implementation of the methodic involves the creation of a computer-oriented learning environment for IT disciplines, in which direct and ICT-mediated learning communication between the main subjects of instruction – teachers and students – takes place. The constructed system of informatics learning tools, interconnected with the informatics competencies of prospective mathematics teachers, provided an opportunity to identify the leading tools (table 1).

The last stage in the model – **the result** – is interlinked with the previous one. The increase in the level of informatics competencies of prospective mathematics teachers is considered both as a current result, which is diagnosed in the process of formation of informatics competencies, and as a component of the overall result of professional training, which is diagnosed after the completion of the formation process. At this stage, the diagnostic tools are not specified because they are part of the teaching tools.

According to the constructed model of computer-oriented methodic for informatics teaching of prospective mathematics teachers aimed at the formation of their informatics competencies, it is possible to define particular methodics: methodic for forming basic informatics competencies, methodic for forming competencies in systems administration, computer networking, cyber security and Internet of Things, methodic for forming competencies in web and cloud technologies, methodic for forming competencies in programming and computer games development, methodic for forming competencies in systems analysis and databases.

In our quest, therefore, the method has evolved from the application of appropriately selected groups of teaching methods – learning strategies as sequences of effective teaching methods used in a purposeful and flexible way, which are increasingly automated but remain consciously applied – through a methodical system to a system of methodics: teaching, forming and using. But the method continues to take a step further. What will it become in the future?

4. Instead of conclusion: Quo vadis?

Informatics is like a two-faced Janus – fundamental and applied, classical and innovative, it is always at the forefront of cognitive science advances, because the meta-method of the learning process is information interaction, and human, animal and machine learning are the methodological basis of modern informatics. That is why, leaving the art of human teaching behind, we associate the future of learning sciences precisely with informatics. What will be the learning systems of the future?

1. B. F. Skinner's key idea – automated learning – is once again returning from semi-obscurity, but no longer in the form of "hard" programmed learning with a fixed algorithm, but through machine learning of mathematical models of neural networks: instead of teaching humans "think like machines" we will teach machines to think like humans. Adaptive learning platforms dynamically adjust the way instructional content is presented to students based on their responses or preferences. Adaptive learning is increasingly dependent on large-scale collection of learning data and algorithmically derived pedagogical responses. Methodical systems for adaptive learning are our immediate future which is already knocking at the door.

2. Methodic as an implementation of a methodical system of learning is embodied by the teacher, who adapts the methodic to a specific fast-changing environment with a great uncertain factor – the person who learns. Full achievement of the learning objectives is only possible if the student is fully modelled: the more adequate the student model is, the more fully the learning objectives are achieved through appropriate learning activities, but the more complete the model is, the more difficult it is for the teacher to work with it – up to the point of inability to select the learning activities promptly. The contradiction between the simultaneous need for completeness and ease of use of the model can be overcome by automating its construction with machine learning: without claiming to understand the

internal structure of the model or even how it is constructed, we will trust it because its behaviour coincides with that of the student in learning. Learning support systems and other digital tools provide the opportunity to collect an extremely big amount of data on any component of a student's learning activities. Digital credentials include different but related strands, such as digitalization of traditional diplomas and granular digital microcredentials, and other digital artefacts will help us. The big data generated in the learning process and the student models built from it will become an integral part of adaptive learning methodical systems.

3. In the somewhat more distant future, updating the tools as part of the learning technology associated with the proliferation of educational applications of deep machine learning (AI education applications). These systems analyze large amounts of data beyond simple algorithms. They are taught to identify and classify input patterns, probabilistically predict, and operate unsupervised (and are able to come up with unanticipated results). Examples of applications are specialised chatbots, natural language interfaces, virtual personal assistants, etc. – wherever precious human resources are spent on algorithmic actions. Under the influence of artificial intelligence technology, the profession of higher and secondary school teacher will also change in a predictable, but still hidden, way.

4. The transition to natural language communication as we are used to it is the next step that intelligent technologies are preparing for us: conversational user interface (CUI) is a high-level design model in which the user and machine interactions primarily occur in the user's spoken or written natural language. Sophistication of the CUI can vary from understanding just simple verbal utterances to handling complex multiturn interactions.

5. If we manage to avoid falling into the uncanny valley trap [21], in the process of approaching the ways in which human beings and software-hardware interact, we can move on to fine-tuning the student model by their emotional state. Emotion artificial intelligence technologies (also called affective computing) use AI to analyze the emotional state of a user (via computer vision, audio/voice input, sensors and/or software logic). It can initiate responses by performing specific, personalized actions to fit the mood of the user.

6. Artificial intelligence and quantum computing are now emerging from the black box into a grey area, but they are jointly influencing the future of learning. How AI and quantum computing may alter methodic's future – this is still a question for science fictionists and futurologists, and it is the task of cognitive scientists to illuminate this grey area by moving from idea to method.

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