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THE VIRTUAL SCIENCE TEACHER AS A HYBRID SYSTEM: COGNITIVE SCIENCE HAND IN HAND WITH CYBERNETIC PEDAGOGY

Boris Aberšek,
Bojan Borstner,
Janez Bregant

Abstract. *The findings of cybernetic pedagogy and didactics developed in the 1970s, which were in those times limited due to poor technological capabilities, are taken as a starting point in this research. A revised version of cybernetic pedagogy is proposed and is used to develop the hybrid cognitive model presented. It is not based purely on the symbolic notation of the teaching algorithm alone, as done in the past, but also on the connectionist model of our cognition, which draws on the brain's characteristics and their physiological and functional structure, such as parallel data processing, content associative memory and divided presentations. The learning process algorithm can be, on the basis of this idea, re-defined as a hybrid cognitive model, i.e. a combination of a symbol system and a neural network, and named mRKP.*
The article concludes that an intelligent artificial tutor can independently, i.e. without the need for reprogramming, accommodate the learning process to the needs and possibilities of an individual student if it uses mRKP as its basis, and can eventually replace a human tutor in some situations, but a human teacher must decide where and when it should be used.

Key words: *cybernetic pedagogy, cognitive science, hybrid systems, learning algorithm, e-learning material.*

Boris Aberšek, Bojan Borstner, Janez Bregant
University of Maribor, Slovenia

Introduction

It can be argued that teaching is something unique, unpredictable, and closely related to a person as an individual in a society. Formal constants can be established for this individual, on the basis of which they are objectivised and formalised. By writing them down in the form of a mathematical model, conditions are created for the development of a *virtual teacher* or intelligent e-learning material. The starting point or an example of this kind of naturalist approach to the development of an artificial tutor is the modern philosophy of mind, cognitive and neuroscience.

On the presumption that there is a correlation between a human and a machine in the sense of a naturalist basis and a reductive path which brings us to it (Dreyfus, Dreyfus, 1986), it is argued that it is possible, with certain limitations and simplifications, to create an intelligent autonomous system (programme, intelligent tutoring system) capable of learning, adapting to new circumstances, and at the same time implementing critical self-evaluation (Bechtel, Abrahamsen, 2002; Bermudez, 2010; Aberšek, Bregant, 2012). Since a positive answer to the question *can the human mind and learning be formalised and reduced to the language of science* is essential for the success of our research, an attempt will be made to prove this by using revised cybernetic pedagogy and didactics (Bregant, Aberšek, 2011).

Society is defined by interrelations between its elements, i.e. the individuals that form it. These interrelations are highly complex and thus cannot be addressed in their entirety, that is why this social reality can never be understood entirely. In order to be able to understand society at least partially, we need to examine how it is influenced by the physical environment, culture and interpersonal relations, since each of these generates social values

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and institutions that in return change society; for example, education affects the attitude towards one's surroundings (it ultimately also affects the economy) and thereby changes cultural relations and the entire society. In this context we are mostly concerned about the social development of an individual and their behaviour in the specific cause-and-effect relationship of a teacher and student as is shown in the process of education (Lamanauskas, 2012).

Cybernetics and Society

Couffignal (1933), one of the pioneers of cybernetics, considered it "the art of ensuring the efficacy of action" and Wiener (1948) defined it as "the scientific study of control and communication in the animal and the machine". A less poetic definition describes it as the science of dynamic time-dependent relations between the parts and a whole and the parts themselves (Müller, 2008). Cybernetics is used in technical and natural sciences as well as in social studies and education (Müller, 2011). Its most important field of use is *computer science*. Because cybernetics is so closely connected with the concepts of structures and levels of organisation, we need to clearly define its elements. The interaction of these elements is shown in the figure below.

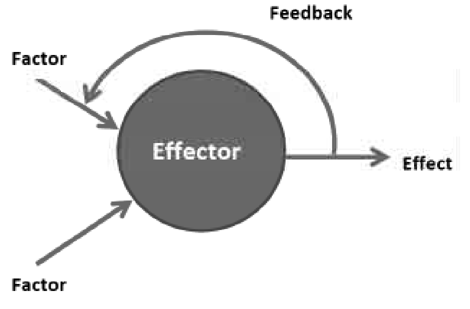

Figure 1: Simple cybernetic system.

An effector[1] is a mechanism that produces certain *effects***.** *Factors* (stimuli) are conditions needed for their operation. *Feedback* is a phenomenon by which effects (output) influence the effector (input) via factors. The purpose of the effector is to achieve a certain/desired effect. There are two types of effectors, *constancy* and *tendency* effectors. The first type tries to keep the effect at a constant level, while the other type tries to move the effect toward a maximum level. The majority of the physiological mechanisms that help to maintain internal equilibrium in living organisms are constancy effectors.

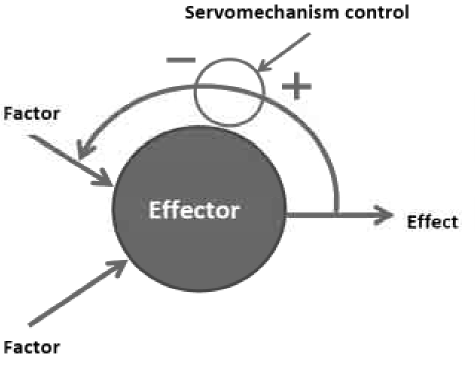

Figure 2: Cybernetic system with a servomechanism.

1 An *effector* has a different meaning in different fields; in technical sciences it is also called an *actuator* and represents a device that transforms input signals into motion; in biology it can be a molecule that binds a protein and thereby modifies its activity, or a muscle that is capable of responding to stimuli.

Another important element in cybernetics is also a *regulator*. It refers to a part of the constancy effector that maintains equilibrium at close to an ideal value of the feedback loop. It can also include a *servomechanism,* which represents a control that is external to the system and influences it as a feedback loop in the sense of modifying its values, as is shown in the figure below.

This type of servomechanism is central to the science of physiology because it takes into account the existence of various levels of organisation in living organisms and their distinctive features; regulated systems of which it is a part are found at all of the mentioned levels. For example, at the molecular level, a set of enzymes necessary for a particular biochemical reaction can be regarded as a regulator. This regulator is influenced by an external control – servomechanism – from the next level up, in this case, the cell, which, for example, determines how a neuron maintains the cell membrane potential. But this regulator is also influenced by a servomechanism from the next level, i.e. the organ to which the cell belongs. This organ is subject to the external control from the next level, and this continues for the entire organism which is influenced by information from its external environment. The described chain of servomechanisms is the result of the evolution of living structures; an organism is thus an open system since information flows down to every level from the level above it and vice-versa (Müller, 2008; Müller, 2011). It must be noted that in contrast to the *structural information* supplied by the genes that can be modified by the environment and thereby produce a unique individual, the *circulating information* is carried mainly by neurons and glands of the endocrine system. While structural information serves to distinguish living beings, for example to distinguish a person from a monkey, circulating information serves to maintain the organism's overall structure and the integrity of each of its levels. By accomplishing its own purpose, each of these regulated systems helps to accomplish the purpose of the system as a whole.

Cybernetics thus teaches us that life is both a system and information, whereas it is presumed that a *machine is only a system that "feeds" on information*. If we turn a computer off, it will no longer be able to use the information stored in its memory, but it will still be a computer ready to work as soon as we turn it back on. But if we, for example, withhold food from a plant or an animal, it will quickly become an inert body that is dying since its structure coincides with the energy that feeds and transforms it, i.e. supplies it with information. Despite this, further on in the article, similarities will be looked for and argued for between natural and artificial intelligence on the basis of the fundamental findings in cybernetics, with an emphasis on modern trends in cognitive science that swears by the connectionist approach to considering and creating "thinking machines";[2] the authors believe that this gives standard cybernetic pedagogy a possibility for further development. One of the artificial teacher's (computer system) main advantages is that it can prepare a specifically tailored curriculum (teaching system) for each student and, based on that, provide a correct evaluation of the individual's achievements.

Cybernetic Pedagogy

Let us now try to transfer the mentioned general principles of cybernetics to the field of education. Cube (1982) set the cybernetic foundations for learning and teaching. Frank and Mader (1971) developed the so-called "*cybernetic pedagogy*" that was based on natural sciences. Cybernetic pedagogy is the science of how a *learning process* can be influenced. The fundamental goals of cybernetic pedagogy are therefore the following:

- identification and analysis of teaching and learning processes expressed in partial systems, and their function in objectivising the educational process; this means the transfer of all activities from human to technical systems or computer programmes;
- analysis of relations and effects between objectivised (technical) and non-objectivised (human) systems of the educational process, for example, evaluation of the interaction between a human teacher and e-learning material with the purpose of achieving set didactic goals;
- explanation of the relations between different forms of partial systems in a given educational system.

2 Connectionism models mental phenomena and consequential behaviour with the help of interconnected networks of simpler units.

According to Frank and Mader (1971), it is possible to formalise or objectivise the learning process as an educational algorithm and express it as a mathematical logical function with the following five conditional variables: *L* – learning material, *M* – media, *P* – psychological structure, *S* – social structure, *Z* – setting learning goals and *B* – teaching or learning algorithm, i.e. a system connecting all the afore-mentioned elements in an indivisible whole. Accordingly, the teaching-learning process must be subject to supervised and guided cybernetic models, as shown in the figure below.

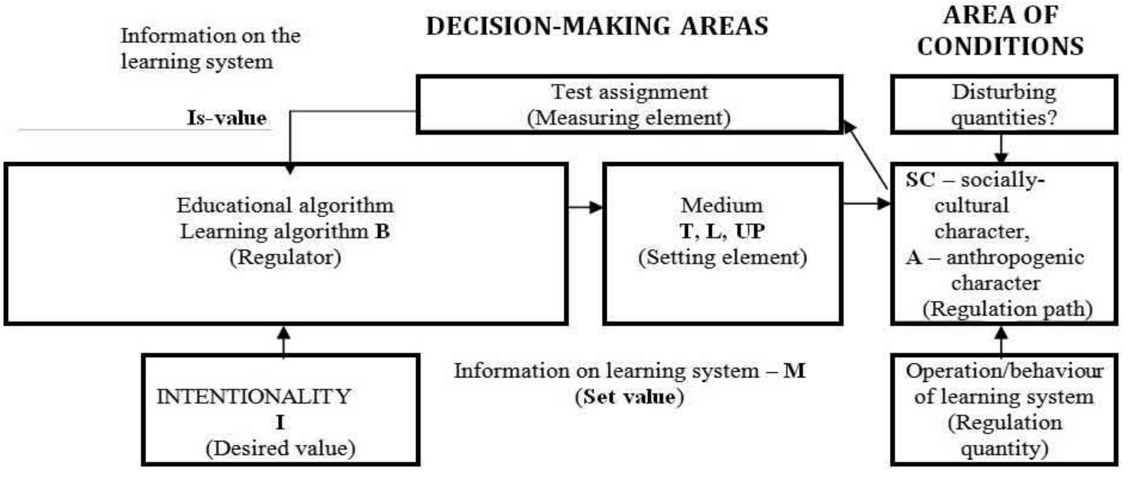

Figure 3: Elements and functions in a teaching-learning process applied in cybernetic pedagogy.

A learning process can also be (technically) realised as a learning programme (*intelligent tutor*) (Frank, Mader, 1971; Frank, 1999); if so, it has to include a *learning algorithm B* formally written in *symbol form* with a mathematical logical function with the presented five conditional variables:

$$B = \mathrm{f}\,(Z, L, M, P, S)$$

Thus, from the viewpoint of cybernetics, the teacher and students, learning process and the organisation of lessons are only a subsystem of the entire education system. A *teacher* is a subsystem functioning as a *transferor* and a guide who holds plans and provides information. A *student* is a subsystem functioning as the *guided one,* one who receives, processes and stores information, and responds to it or is guided by it. Teaching within this meaning is a deliberate interaction in which students and the teacher change their characteristics and their actions in a quantified and qualified manner, and can therefore be considered as an adaptive system; in other words, learning is a process that leads to adaptive changes in the system. Changes that are a consequence of learning make it possible for the *same population* to solve the *same tasks* faster and more successfully than before the learning process (Aberšek, Kordigel Aberšek, 2011; Hus, Kordigel Aberšek, 2011).

Mistakes in Cybernetic Pedagogy

When it was first developed and its authors attempted to realise it in practice, cybernetic pedagogy must have been considered a breath of fresh air in the standard didactic thinking. Despite being, in a way, ahead of its time, it has now been almost completely forgotten due to the following three reasons:

1. It paid too much attention to how a learning process could be formalised or objectivised as an educational algorithm and expressed as a mathematical logical function with which the learning process could be influenced (optimisation of the learning process) and did not pay enough attention to the learning process itself.

2. It disregarded the differences between the distinctive psychological and pedagogical features of mental operation on one side and the characteristics of technical systems on the other. Subjugating anthropological characteristics to technical models with the reasoning that the same kind of organisation and laws apply to human thinking as they do for the world of machines is a concept otherwise also known in *structuralism* (Searle, 1983a; 1983b). Even though the belief that by using cybernetic methods, based exclusively on symbol systems, higher mental activities and processes can also be formalised, modelled and automatically supervised is not uncommon (Cube, 1982; Frank, Mader, 1971), not enough attention is paid to the distinctive features of the educational field in which the student is not only the object of teaching but also the subject of its own control and modification; this is also true when not only one "ideal" student but several students who differ in their cognitive abilities, and thus require different methodology and didactic approaches, are included in the process. (Jank, Meyer, 2002). What is striking are the differences between the objectives of human learning and cybernetic learning paths, i.e. between the demand for developing higher, independent mental activities and strictly supervised learning, between generalised, synthetic thinking and particular analytic learning processes, between creativity, differentiation, individualisation and automated learning. It is not easy to abstract from the learning material's content and value and to reduce it to symbols, formulas and models without turning it into formalistic knowledge – into educational clichés. Despite all of this, today the authors cannot agree with Gilbert's recommendation: "If you do not have a teaching machine, do not get one…", but should agree with his warning: "Never allow the machine to give commands to the programme" (Gilbert quoted in Strmčnik, 1978, p. 68).
3. In programming the learning process according to its principles there were particular limitations due to the level of technological progress at the time (Winograd, Flores 1986, Dreyfus, Dreyfus 1986); therefore, there was not enough available and capable hardware and software.

Results of Research (Revised Cybernetic Pedagogy)

Let us try to reject the reasons above and thereby bring cybernetic pedagogy back to life.

Rejection of Reason no. 1

Answers to the question of what a learning process should be like, neglected by cybernetic pedagogy, can be found in the *didactics of learning theory* (Heimann, 1976; Reich, Thomas, 1976; Straka, Macke, 2006; Jank, Meyer, 2006), which places the "structural analysis of lessons" at its centre; with this cybernetic pedagogy can be enriched, and the criticisms rejected if need be. Heimann came up with a surprisingly simple idea of how to set the "basic framework" of a lesson. In order to do so, a particular learning process must be observed closely enough to be able to extract the "*formal constants*" from different types of lessons. Thus established constants can become the guiding constants in analysing as well as planning the lessons (Heimann, 1976).

This is based on the realisation that the teacher has to always think about their lesson, what its *goals/intentions* are, what the *learning topic is*, which *methods* are best suited to achieve the goals set and which *teaching aids* will be needed. This can be defined with four essential characteristics: intentionality, topic, methodology and tools; and as will be shown later on, two more can be added. For all four constants the *teacher* has to decide what it is they want; this is therefore called a *decision making area*. In their decisions the teacher is limited by certain characteristics they or the students already have and can therefore not be changed. They are *anthropogenic*, i.e. inherent to human beings, and *socially-cultural characteristics* which are the result of fast or slow social changes (historical memory). Regarding these two constants the teacher is, in a sense, a "victim of the situation"; therefore, this is called the *area of conditions*.

The didactics of learning theory has at its centre a relatively simple structured network made up

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of six phenomena, which categorises those phenomena and places them in the whole via a system of symbols that enable a comprehensive inclusion of all the essential circumstances and decisive tasks of the lesson.

After almost forty years since this model of a structured lesson was presented, it is clear that the statement, which was regarded as stemming from it, is the first problem and the source of all the problems: *lessons are an example of a formally constant structure or a structure whose validity is unlimited* (Heimann, 1976). This thesis is untrue since there are no structures whose validity is unlimited; they are always created by humans through their practical operation in a certain time-specific social system. For example, emphasising certain teaching aids in a model can thus only be explained on the basis of current social-political circumstances and school policy.

Another problem is represented by the fact that two entirely different areas are included in the model of a structured lesson from the viewpoint of symbolisation. It is relatively simple to formalise decision-making areas or to write them in symbol form with a limited number of modifications of individual factors since the number of methods for achieving the set goals is limited, as is the number of teaching aids and topics. Problems with formalisation occur in the area of conditions when we no longer talk about a certain specific process with clearly defined goals and limited quantities of content, method and teaching aids related to them. Here we are faced with a completely open system of anthropogenic and socially-cultural characteristics that are usually entirely individualised: anthropogenic characteristics are wholly connected to a human being as an individual, whereas the socially-cultural characteristics are wholly connected to certain groups and communities on the basis of their social and cultural relations (Bateson, 1979; Anderson, 2007).

Therefore, since lessons are supposedly a structure with unlimited validity, which is not true, and because cybernetic pedagogy at those times was not able to symbolise the area of conditions, and dynamic models used for programming had not yet displaced symbol models, the criticism was made that it does not provide answers to questions regarding what a learning process should be like. It is clear that every model should be, at least partially, dynamic, which means it should include socially-cultural as well as anthropogenic characteristics and development levels and also take into account the level of society's technological development (in information and communication technology), students' abilities and habits, and all other influential factors that co-create the lesson. Didactics and its models must follow continuous changes and adapt to all changes. The goal of each model must be to maximise the quality of the student's knowledge. The learning process is indeed an indivisible union between the teacher and the student or between teaching and learning; however, the latter is more important.

The use of an unfinished concept and the impaired transfer of a model of a structured lesson into practice were regrettable, and it is therefore clear to see why it was buried by the three reasons mentioned. However, its starting points provide almost ideal possibilities for further development, especially when taking into account the modern connectionism trends in the field of cognitive science. This is why, later in the article when the other reasons are rejected, more attention is paid to this and to the possible directions of its further development (Reich, Thomas, 1976; Aberšek, 2012).

Rejection of Reason no. 2 (solution to the philosophical problem)

In structuralism it is common belief that the same organisation and laws apply to human thinking as for the world of machines; critics consider this as ignoring the differences between the distinctive psychological and pedagogical features of mental operation on one side and the characteristics of technical systems on the other. To overcome this criticism and take into account in the modelling of higher cognitive processes the distinctive features of the educational field, where the student is not only the object of teaching but also the subject of its own control and change, structuralism must be replaced with modern *cognitive science* as the fundamental premise (Bermudez, 2010; Winograd, Flores 1986; Markič, 2011).

Modern cognitive science developed from cybernetics in the 1950s and has undergone numerous paradigmatic changes since then. In previous years, cognitive science's study of mental processes has too often been done only from the viewpoint of one of its constituent disciplines, either cognitive linguistics, cognitive neuroscience or cognitive anthropology. But today the prevailing conviction is that only an equal treatment of all its constituent fields – philosophy, psychology, linguistics, social sciences, computer science and neuroscience – can ensure an adequate explanation of mental processes. Cognitive scientists are trying to transfer their findings into practice – particularly in the fields of teaching and studying, co-working, machine learning and decision-making. *Connectionism* (Bechtel, Abrahamsen, 2002; Anderson, 2007; Horgan, Tienson 1996), one of the directions in cognitive science, was developed in the mid-1980s as an alternative to *symbol models* (traditional computer paradigm). This alternative computer paradigm is based on an analogy between a digital computer and the mind, according to which thinking constitutes a special kind of symbol calculation. The connectionist model of the mind is a discreet dynamic system with the same kind of learning algorithms. Their main characteristic is that they are composed of simple units, i.e. idealised neurons, which are interconnected. Each unit has a certain activation value that is forwarded to other units via bonds of varying degrees of strength and thereby contributes to an increase or decrease in their value. The entire process is performed in parallel and does not need a central part for its control. Such a network learns the selected cognitive tasks in the learning process by changing the strength of the connections between units on the basis of a learning rule (algorithm). The choice of the network's architecture and the learning algorithm depends on what kind of cognitive task we would like to model using the network, or how neurologically credible we would like the model to be.

Since both standard symbol as well as connectionist models suffer from many imperfections, Horgan and Tienson (1996) proposed a new theoretical framework for cognitive modelling, i.e. the *theory of dynamical systems*, which draws on connectionism but also on certain fundamental findings of symbol models, particularly the importance of syntax. With dynamical systems and this kind of modelling of the human mind, theorists are trying to answer long-standing philosophical questions, such as *what is a conscience, where is the source of knowledge, what are the mechanisms of perception, remembering and learning, what is the role of language, what is the relation between physical and mental, i.e. between the mind and the body* etc. Increasingly powerful computers have become a powerful weapon that enables the empirical testing of theoretical ideas and the developing of models that, more or less, correspond to human cognitive functions. Dynamical systems are essentially a cross between symbol and connectionist (network) models and are therefore known in short as hybrid models; one of the most refined models is Anderson's ACT-R (2007).

Findings so far have shown that there are different types of learning; they can be divided into four groups, shown in the figure 4 below, with regard to what type of memory is being used, whether new symbol structures are being created or whether only sub-symbols are being inserted in already existing ones (Anderson, 2007, p. 92).

	Declarative memory	**Procedural memory**
Symbolic learning	Learning facts	Acquiring skills
Sub-symbolic learning	Reinforcing	Conditioning

Figure 4: 4 types of learning.

1. *Learning facts:* New memories can be created in declarative memory. This is memory in the strict sense of the word; this is what most people understand as memory. This is the only way of learning that results in new conscious memories.
2. *Reinforcing:* When creating new declarative memories we can also work on making these memories more accessible. This process of learning is called reinforcing knowledge.
3. *Acquiring skills:* Different types of learning lead to new work procedures (new production rules). Acquiring skills leads to a routine where we perform individual tasks unconsciously, e.g. blind typing or driving.

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4. *Conditioning:* Through experience we learn that particular activities are more efficient in certain circumstances. Conditioning is generally seen as the most common learning process; classic examples are Pavlov's conditioning experiments conducted on dogs (Pavlov, 1927).

As a result, two types of obtaining new knowledge, i.e. symbolic and sub-symbolic learning, must be taken into account in the taxonomy of learning. Since they both have their own specifics, different "tools" have to be used for their modelling. Therefore, when cognitive psychologists look for answers to the question of how does one remember and how does one learn, their starting point is finding the internal mechanism of human thinking and obtaining knowledge (Searle, 1983a, Horgan, Tienson, 1996). In other words, they are looking for the mental process that is related to how integration and information retrieval work. When this process is known, there is only one step left to its formalisation.

To overcome the criticism of ignoring the differences between the distinctive psychological and pedagogical features of mental operation on one side and the characteristics of technical systems on the other, and take into account in modelling higher cognitive processes also the distinctive features of the educational field, where the student is not only the object of teaching but also the subject of its own control and change, structuralism with symbol models must be replaced with modern *cognitive science* with dynamical systems as the fundamental premise.

Rejection of Reason no. 3

The third criticism of cybernetic pedagogy is closely connected to the technological capabilities or incapability's of the period when it was developed. It was based exclusively on the symbolic notation of the teaching algorithm and thus faced insurmountable barriers. By replacing structuralism with cognitive science we can remove this criticism. The latter supports symbol as well as network systems – this is key to programming a learning process, which only works if the formalisation is partially a symbol formalisation and partially a network formalisation.[3] The connectionist models, which draw on the brain's characteristics and their physiological and functional structure, vary from the standard symbol models in certain essential characteristics, such as parallel data processing, content associative memory and divided presentations. On this basis (see Figure 5) the learning process algorithm can be re-defined and named *mRKP*:

$$B = \mathrm{f}_1(I,\ T,\ L\ \mathrm{f}(T),\ LA,\ ME)\ \mathrm{f}_2(SC,\ A)$$

(Two types of functional dependency are included in the equation, f_1 for *decision-making areas* and f_2 for *area of conditions*.) Under this equation the learning process algorithm is expressed as a mathematical-logical function of seven conditional variables:

- *I – intentionality:* Its definition is complex since the goals are essentially connected with the topic; despite this it makes no sense to develop a neutral catalogue of goals (Searle, 1983b). The teachers should themselves determine which orientation patterns and structures are behind a particular goal since it makes a significant difference whether it refers to only knowledge transmission or to creating something new. A reference point for regulating intentionality can also be found in anthropology: Since human behaviour does not exist on its own, but is always a consequence of thinking and emotions, Heimann (1976) defines *thinking, wanting and feeling* (head, heart and hands) or, according to Bloom (1956), *cognition, affection* and *psychomotor skills* as the three *fundamental dimensions of*

3 It is true that only those connectionist models that take place in *continuous time* (not all of them can do this, e.g. hybrid models, such as ACT-R, are discreet systems) are considered real dynamical systems, but hybrid systems suffice for modelling a learning process.

human behaviour. What is of particular importance is their combined operation, which has to be in tune.

- *T* – topic;
- *L* – learning material, which should be seen in a slightly wider sense than in standard cybernetic didactics and is mainly dependent on the topic and closely related to learning aids;
- *UP* – learning aids;
- *ME* – didactics or methodology of lessons in the strict sense. Different topics can be presented in different ways; however, selecting them depends mainly on the desired goals and results of the lessons. This conditional variable is the basic factor in optimising the learning process.
- *SC*– socially-cultural character;
- *A* – anthropogenic character.

What does this mean for the formalisation of classes from the viewpoint of the third criticism and for reviving cybernetic pedagogy?

- *Decision-making areas:* It is relatively simple to formalise the methodology, topic and learning aids or write them in symbol form with a limited number of modifications of individual factors since the number of methods for achieving the set goals is limited, as is the number of teaching aids and topics. The only problem we are faced with is *intentionality*, particularly as regards learning, since a network system instead of a symbol model would have to be used for its formalisation.
- *Area of conditions*: Here we are faced with a completely open system of anthropogenic and socially-cultural characteristics that are usually entirely individualised: the former are completely connected to a human being as an individual, whereas the latter are connected to certain groups and communities on the basis of their social and cultural relations. Since we are no longer talking about a specific process with clearly defined goals and limited quantities of content, method and teaching aids related to them, we must use a network system for their formalisation.

It follows that the same tools and the same work methods cannot be used for the symbolisation of both areas (except for intentionality). Symbol systems can be used for modelling decision-making areas, as was done in the past, while the area of conditions must be modelled using network systems that enable complex individualisation and differentiation of the learning process. Cybernetic pedagogy should be treated and presented as a *hybrid system* since it nowadays combines two different methods of formalisation supplied by the cognitive platform, symbol and connectionist ones, and not as a symbol system as it was treated and presented in the past.

Symbol Systems versus Connectionism

Since the *mRKP* of the learning process is a hybrid system, i.e. a combination of a *symbol system* and *connectionism* (neural networks), let us first look at the advantages and disadvantages of such systems. We will analyse the symbol system in the case of *Eliza*, a computer programme for simple natural language processing, from the early stages of the development of artificial intelligence – AI. Some see it as the first intelligent system, even though the same could be said of The Checkers Program, developed by A. Samuel in the early 1950s, or the so-called *Logic Theorist*, developed a little later by Newell, Shaw and Simon (Copeland, 1993). It should be noted that in 1966, when Eliza was written, *interactive computing*[4] (then only by using the keyboard) was a completely new thing. It would be 15 years before the general public became familiar with the personal computer, and three decades before

4 Interactive computing enables communication between the machine (computer) and human. In the early stages this could only be done via a keyboard; today other elements (e.g. mouse) and other channels (e.g. speech) are also being used.

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most people encountered attempts at natural language processing in PC help systems. The source code was written by Jospeh Weizenbaum at MIT; it was based on the principle of *pattern matching* and it worked by converting answers into new questions. It used a programming trick that enabled Eliza to evoke a special response in situations when no patterns matched. When an incoming phrase with a predominant pattern, e.g. "my", appears, in its response Eliza uses the transformation from the top of the list of transformations and also chooses another transformation from another list; it then saves the results in order to use them when there is no match.

The programme shows considerable lack of comprehension; however, problems appear later when a slightly modified form of the incoming phrase is repeated too many times. Eliza's success depends to a great extent on luck, since the entire system depends on the probability of the right pattern evaluation and the corresponding transformation. What are the advantages and disadvantages of symbol models?

One of the main intuitive advantages of standard symbol computer-based approaches to cognition is a clear traditional notation of cognitive presentations. Presentation is a precise data structure with a semantic context (by taking into account the interior or exterior of a cognitive system). It can be modified and adapted to current needs, and these kinds of symbols are undoubtedly similar to the real world and phrases from the natural language (Fodor, 1983). Their main disadvantage is that symbol structures are not capable of learning, and therefore they are not capable of solving tasks that cannot be written in the form of algorithmic symbol systems.

In a connectionist model the neural networks are composed of elements, so-called artificial neurons, which copy the biological neurons in terms of their structure and operation (Morris, Filenz, 2003). The figure 5 below illustrates the structure of neurons and clearly shows that the structure of an artificial neuron is essentially the same as that of its biological counterpart.

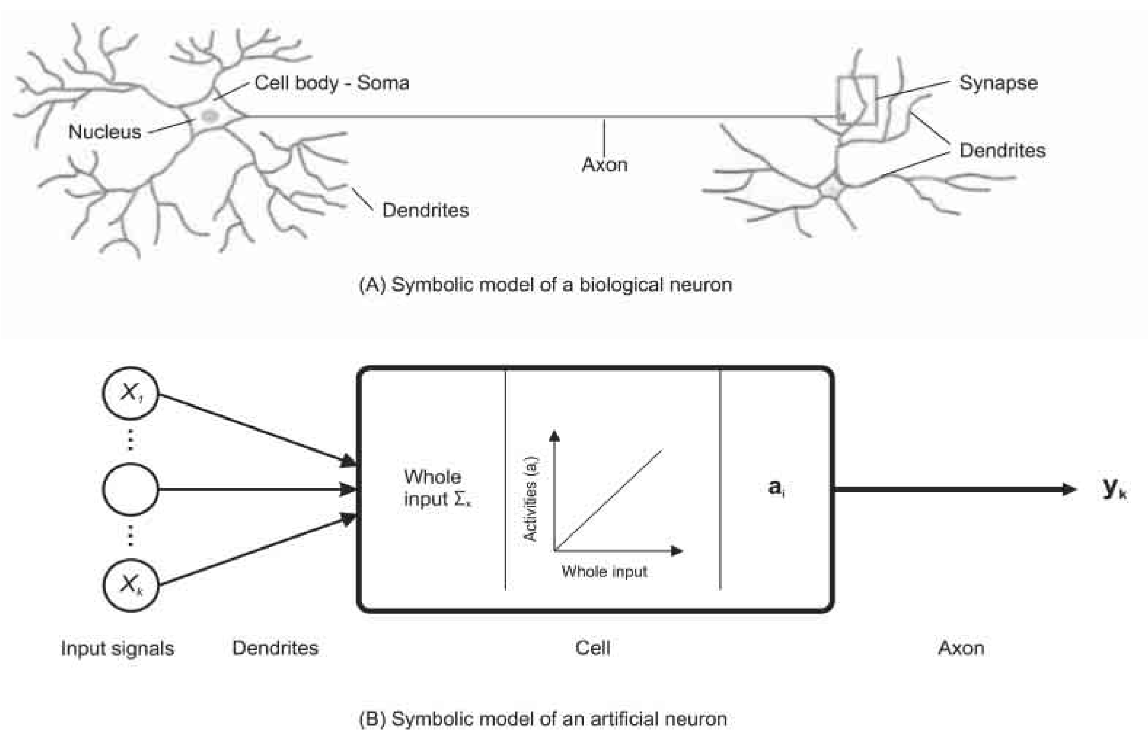

Figure 5: Neuron models.

In an artificial neural network neurons are interconnected in different ways. The main characteristic of a neural network is that it is capable of learning how to connect the input data with the output data. The acquired knowledge is stored in synapses and is called weights. In the learning process individual weights change in order to achieve an optimally balanced neural network. In such an optimally balanced state a neural network is capable of generalisation; this means that it is capable of connecting an unknown input pattern with the correct or desired output pattern.

As shown in the figure 6,[5] the artificial neuron's structure is composed of three basic elements. The first element is a *set of synapses* or input connections; each of them has its own weight (W_{kj}). (Each neuron's input is marked by index *j* and individual neurons in a neural network by index *k*). The second element is an *Adding element*, in which all products of input signals and weights are cumulated. The sum of the neuron's products is marked by the symbol U_k and is called *action potential*. The third element is a *transfer function with an output* y_k. In this element the input is the action potential; the threshold value ($U_k - \theta_k$) is deducted from it. The threshold sets the limit of the neuron activation marked by the symbol θ_k. An artificial neuron model can also be operationalised by transferring the threshold to neuron input. In order to do this input, variables (X_j) need to be expanded for one additional variable with the value minus one ($X_0 = -1$). Weights must also be expanded for one additional weight equivalent to the threshold ($W_{k0} = \theta_k$). The figure below shows the operationalisation of the artificial neuron model or the new synapse added in the artificial neuron model that was inserted at the position with zero index ($j = 0$).

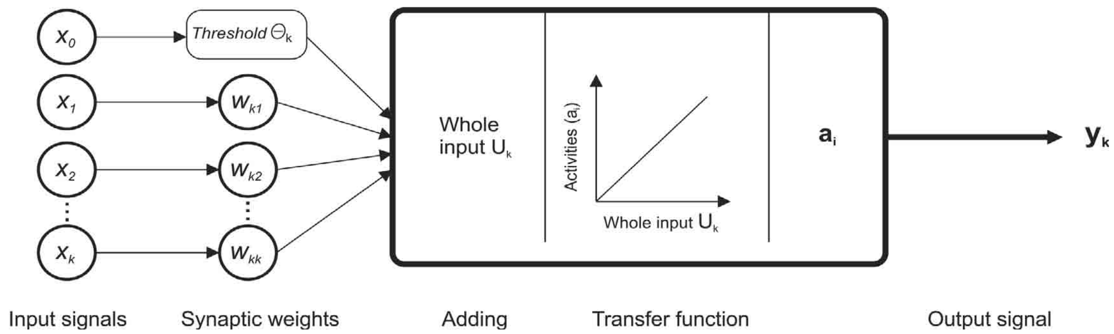

Figure 6: Artificial neuron model and its operationalisation.

The learning process of neural networks is defined as a process in which the free parameters of the neural network, i.e. weights, adapt through the process of encouragement from the environment in which the neural network is performing the desired activities. In the learning process of a neural network different rules or algorithms can be used, such as the Hebb Rule, the delta rule, the competitive rule, the Boltzmann rule, etc. (Bermudez, 2010).

What are the advantages and disadvantages of neural networks? Their main advantage is their usability, even when the input data is incomplete or incorrect, since they can correctly predict the sought after results, provided that the right learning algorithm was selected. The main disadvantage of neural networks lies in the fact that they are not explanatory since they operate on the principle of a *black box* into which data is sent and from which results are obtained. Since there are no predefined rules that would make it possible to set the parameters for an optimal modelling of a neural network (black box structure), and this is more or less left to our own ingenuity and experiences, this can mean that the desired result is not achieved.

It can be concluded that significant theoretical differences between connectionist and symbol models lie in the dissimilar understanding of presentation of knowledge. Presentation of knowledge in connectionism is no longer an internal state that is static, simple and can be described by language. It no longer necessarily forms a symbol system, is made of sub-symbols, divided and context-dependent. Knowledge is no longer presented in the formal notation of a language or logics, but is

5 Adapted from Bermudez, 2010, p. 233.

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stored in weights in neural networks as a consequence of learning. The essential advantage of neural networks compared to symbol systems is that during operation they themselves recognise the rule that connects the output data with the input data. This means that they can learn, and when a neural network is capable of learning, it is also capable of solving tasks for which no prior solutions in the form of consecutive steps, i.e. algorithms, exist.

Since a hybrid model (Anderson, 2007) would ensure the minimalisation of disadvantages and maximisation of advantages of both systems, it will be explored later in the article whether a hybrid *mRKP* system meets this expectation; this will be done in the example of electronic learning material.

Case Study: Intelligent tutoring system – e-learning material

One of the main methodological problems of today's electronic learning material is their inability to adapt to user's demands, needs and, most importantly, their abilities and previous knowledge. E-learning material often has the same scenario, content and goals for all users, regardless of their different abilities and level of knowledge. In other words, all current e-learning material is missing differentiation and individualisation of the learning process from which it is composed (Gur-Zéev, 2005). An answer as to how to avoid this problem can be found in the presented revised cybernetic pedagogy on which the so-called *programmed learning,* developed at the beginning of the 1970s, is based; the latter was enabled by the fast development of industry, science and technology as well as the need for self-education.

Thus, from the didactic point of view, electronic e-learning material should be designed in a way that would enable the student to learn effectively and independently without the direct presence of a teacher; in this way it would come closest to learning with a teacher and would ensure that the student obtains new knowledge in a permanent and high-quality manner (Bregant, Aberšek, 2011). With certain simplifications, the presented *mRKP* model of the revised cybernetic pedagogy would meet this demand immediately and could also be very easily implemented in the current school practice.

Let us have a closer look at the demands of programmed learning and see which of them can be met by the virtual teacher based on the hybrid *mRKP* model.

Definition of Programmed Learning

The beginnings and principles of programmed learning can be found throughout the entire history of didactics. The desire for efficient learning aids and self-education can be found in Socrates, or as Skinner wrote back in 1963, if by some magical invention books were changed so that the second page in a book would only be clear to those who have mastered the first page, a large part of what today requires direct activity by the teacher could be learned by the students themselves (Skinner, 2005).

Programmed Learning and Individualisation

The view that individualisation of e-learning material considers only the way people adopt information or what type of people they are (auditory, visual or kinaesthetic), on the basis of which we prepare e-learning material that suits the highest number of people, is false. Such an individualisation method is part of the essence of electronic e-learning material since it must be interactive and, at the same time, include elements of multimedia. Additionally, such a solution can only be a part of the didactic-methodical differentiation and individualisation where, in addition to the mentioned changing of media, sources and methods can also be changed in order to ensure that electronic e-learning material is acceptable, interesting and effective for every student (Newel, 1990).

Programmed learning offers the following four principles of individualisation (Pritchard, 2009; Dolenc, Aberšek, 2012):

- individualisation of personal pace;
- individualisation of learning content;
- individualisation of teaching methods;
- individualisation of learning support.

Personal pace, also called learning pace, differs in every student. It mainly depends on the individual's prior knowledge, their motivation, learning habits, content understanding and, most importantly, their thinking ability subject to the complexity of the process. Individualisation of the *learning content* offers students several additional side paths with new information that help them overcome certain obstacles on the main learning path or to enhance and expand their knowledge. It enables the following (Gur-Zéev, 2005):

- inserting information and tasks of varied levels of difficulty;
- predicting obstacles and planning their avoidance by choosing a different learning path:
- returning to content not mastered by the students;
- giving additional assignments to students who do not understand something;
- shorter and longer learning steps.

The most widely accepted principle in today's e-learning material is the individualisation of *teaching methods* (forms, means and techniques). When programmed learning first appeared, it was not possible to add interactive and multimedia elements, whereas today we cannot imagine e-learning material without images, sound, animation and video.

The last dimension of individualising programmed learning is the individualisation of *learning support*. A question that always arises is how to provide learning support for students when they need it. Most problems can be avoided with good programming, appropriate instructions, suggestions, impulses, encouragement and additional explanation; nevertheless, individuals and groups can still come across certain difficulties. Experts' views on how machines cope with this are different. In the past, some argued that machines would soon be able to provide direct learning support to every student at any time; but this is still not possible today. It is obvious that the path to individualising learning support lies in a good programme, but it is also true that the progress and development of artificial intelligence, as well as the accessibility of this technology in the educational process, is still in its early days. Smaller problems that could be encountered by students during learning can be avoided by testing, but bigger problems can only be resolved by a teacher. Although software can enable the student to come back to the problem several times to try to solve it, it cannot discover the student's weaknesses on its own. Concrete or personal help by the teacher is thus still a big advantage (Aberšek, 2012).

Discussion

From the viewpoint of pedagogy and didactics, the electronic e-learning material should be designed so that it enables students to learn efficiently and independently without the direct presence and help of a teacher. The preparation of such e-learning material must take into account and include the following essential functions of a learning system (Dolenc, Aberšek, 2012):

- presentation of relevant information, e.g. learning content, initial questions, assignment, problem, instructions, evaluation, value judgments;
- adopting, storing and analysing information presented by the learning system, e.g. information on reactions, modes of behaviour and reactions, and answers;
- evaluating the condition diagnosed by the learning system and its comparison with the planned target value;
- selecting suitable alternative learning steps/programmes for further influence on the learning system (feedback, learning support for the learning system etc.).

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The following essential goals of cybernetic pedagogy must be met:

- identification and analysis of teaching and learning processes expressed in partial systems and their function in objectivising the educational process; this means the transfer of all activities from human to technical systems or computer programmes;
- analysis of the relations and interactions of objectivised technical and non-objectivised human partial systems of learning processes, e.g. the interaction between a human teacher and e-learning material, in order to meet didactic goals;
- explanation of relations between different forms of partial systems in a given educational system.

Before beginning to prepare e-learning material, a precise algorithm (*mRKP*) that follows the set learning goals and provides unambiguous answers to all functions and requested goals must be prepared. The right use of all the mentioned didactic characteristics ensures that the electronic learning material will be as close as possible to the standard teaching and learning. Finally, attention should be paid to previously defined learning goals since it is pointless to prepare e-learning material without them. With well-defined learning goals in electronic learning material the student can be clearly informed what they can expect from a certain learning programme; well-defined learning goals are also a good starting point for preparing tests of knowledge and activities that encourage interaction in the learning process. Usually, e-learning material contains several learning goals, and their number depends on its extensiveness. Learning goals are often divided into sub-goals. Basic goals refer to e-learning material as a whole, whereas the sub-goals refer to individual sets of content. In determining learning goals special attention must be paid to their *escalation*. Most commonly used is a hierarchy of goals with *general* (directional) goals at the top, followed by *interim* (partial) goals and *operational* (fine) goals at the bottom. Theoretical specialities apply to the hierarchy of goals, particularly the cohesion of parts and the whole, specific reciprocal relations and interaction, and hierarchical structure (Jank, Meyer, 2002).

E-learning material prepared in this way has certain structural similarities with the principle of action research in which every research step is followed by continuous evaluation, and, in accordance with the grade obtained; the research plan or even the initial research idea can be changed (amended) (Reinmann-Rothmeier, 2003; Aberšek, 2012).

Conclusion

The presented hybrid *mRKP* model does not only symbolise the learning process but also the social environment in which it takes place. The proposed formal lesson model presents a starting point for the development of an independent, adaptive tutor (virtual teacher, computer programme, artificial teacher) that can independently (and without the need for re-programming) self-adapt the learning process to the needs and possibilities of individual students as does a human teacher.

Information-communication technology (ICT) is already an integral part of all school systems, while e-education and e-material are notions without which we cannot imagine schools today. This is why it is even more important that electronic learning material is prepared in a high-quality manner and is intended for active education without the direct presence of a teacher or with their "limited" help, and is not an end in itself, as is often the case today.

We should not be satisfied with copied content from student books and added multimedia and interactive elements since this can cause more damage than benefit. Although such preparation of e-learning material is quick, simple and cheap, it is not necessarily didactic. Electronic learning material is didactic when it enables an individual to achieve the desired goal by stepping onto a path that ensures gradual progression and one's own, personal pace; in short, when it suits the individual. The preparation of electronic learning material demands differentiation and individualisation of individual participants and continuous evaluation not intended as an assessment, but with the purpose of leading the individual toward the goal on the path that is most suitable for them.

Modern research in education processes shows that the highest educational goals cannot be achieved without active participation by the student. In order to follow the appropriate development of the student's potential it is therefore of utmost importance that we continuously follow and evaluate the educational process, and implement the necessary corrections when needed. This way of working is to a great extent enabled by modern (intelligent) electronic learning material, but only if it is correctly designed (from the viewpoint of pedagogy and didactics) and technologically implemented. Such material must also, among other aspects, evaluate the user and upon poor results change the path to achieve the planned goals. With cleverly set goals not only can the participants obtain the prescribed knowledge suitable for their level, but this can also enable continuous adaptation of the path towards those goals. The authors believe electronic learning material designed on the basis of the hybrid *mRKP* model can lead to the fulfilment of all of these requirements.

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Boris Aberšek	PhD., Professor, University of Maribor, Faculty of Natural Science and Mathematics, Koro ka 160, 2000 Maribor, Slovenia. Phone: +386 2 2293 752, Fax: +386 2 2518 180. E-mail: boris.abersek@uni-mb.si
Bojan Borstner	PhD., Professor, University of Maribor, Faculty of Arts, Koro ka 160, 2000 Maribor, Slovenia. Phone: +386 2 2293 797. E-mail: bojan.borstner@um.si
Janez Bregant	PhD., Associate Professor, University of Maribor, Faculty of Arts, Koro ka 160, 2000 Maribor, Slovenia. Phone: +386 2 2293 790. E-mail: janez.bregant@um.si