

# SCHOOL AS A (MULTIMEDIA SIMULATION) PLAY: USE OF MULTIMEDIA APPLICATIONS IN TEACHING OF PATHOLOGICAL PHYSIOLOGY

*J. Kofránek, M. Mateják, S. Matoušek, P. Privitzer, M. Tribula, O. Vacek*

Laboratory of Biocybernetics, Institute of Pathological Physiology, First Faculty of Medicine, Charles University in Prague

## **Abstract**

Nowadays, the old Comenius's motto – "schola ludus" ("school as a play") has found its modern use in interactive educational programs using simulation games. Connection of the Internet and a multimedia environment serving as an audio and visual user interface with simulative models makes it possible to have a graphic feel in the virtual reality of the problem currently studied, upon connecting to the magical Internet network. By means of a simulation game it is possible to test, without any risk, the simulated object's behaviour – e.g. trying to land with a virtual airplane or to heal a virtual patient. Through the simulation game we can test the behaviour of individual physiological subsystems, both under normal conditions and in the presence of a disorder. The Atlas of Physiology and Pathophysiology (<http://www.physiome.cz>), designed as a multimedia-teaching tool, which helps to explain the function of individual physiological systems, causes and symptoms of their disorders in a visual way through the Internet is one of the projects in which we want to utilize new opportunities of multimedia and simulation models. Development of the Atlas requires cooperation of many professionals: Starting from experienced teachers whose design provides the foundation of quality educational applications, system analysts responsible for creating simulation models for educational simulation games in cooperation with professionals in their field, artists creating the visuals, and finally up to programmers who "knit" together the whole application to achieve its final form. For the inter-disciplinary collective creation to be successful, specific development tools with sufficient technical support must be used in each phase of creation; such tools allow for component-based creation of simulation models, creation of interactive multimedia and their final interconnection into a compact unit based on the given design. Creative interconnection of the various professions is the key to success. The Atlas of Physiology and Pathophysiology is a freely available application. Any form of cooperation in its gradual development is welcome.

**Keywords:** Internet, Multimedia, Simulation Games

## **Schola Ludus in a Modern Garment**

*Multimedia programs with simulation components* for educational purposes are not only a replacement of classical textbooks. They serve as an entirely *new instruction aid* making it possible to explore the studied problem in virtual

reality through instruction simulation games, thus bringing quite new possibilities to explain complex problems – and this is precisely the point where the old credo of John Amos Comenius “Schola Ludus” (School as a Play), promoted by this European pedagogue as early as in the 17th century, finds its modern application.

Many instruction-oriented *simulators of individual physiological subsystems* for free pedagogical use can be found on the Internet. Thus for example, the simulator ECGsim makes it possible to study the generation and spreading of electric potential in heart ventricles and to study the mechanism of origination of the ventricular complex QRS in various pathologies (from impulse conduction disorders to ischemias and infarctions) [14]. The heart simulator from Columbia University allows for observing the pressure-circulation curves in heart ventricles in various cardiac pathologies (valvular defects, left-sided or right-sided failure) [2]; anaesthesiological device simulators from the University of Florida provide the possibility to administer anaesthesia to a virtual patient [17] and to observe appropriate physiological responses (however, more complex simulators require paid access) etc.

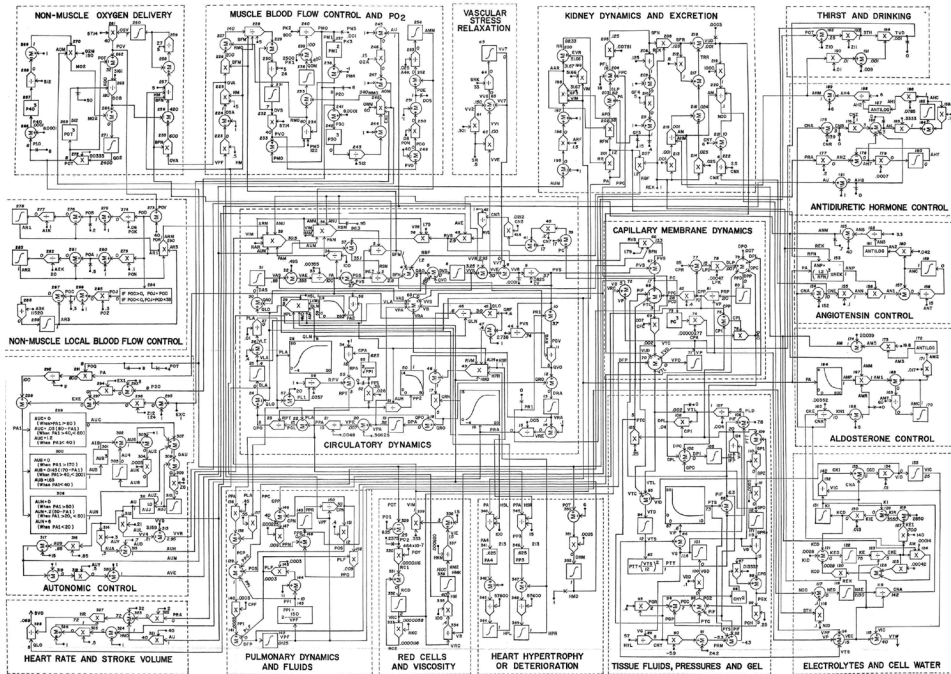
### **Complex Methods of Integrative Physiology and Teaching**

Complex simulators are of large importance for teaching of pathophysiology and study of pathogenesis of varied pathological conditions; such simulators include *models of not only individual physiological subsystems but also their mutual connection into a more complex unit*.

Prof. Guyton was a pioneer of making these models. In 19972, he published an article [6] in the journal Annual Review of Physiology, whose form quite surpassed the usual forms of physiological articles of those times at the very first sight. An extensive diagram pasted in as an attachment was used as introduction, showing interconnection of essential subsystems that have an effect on circulation, by means of special symbols expressing mathematical operations.

Guyton’s model was the first extensive mathematical description of physiological functions of interconnected subsystems of an organism, and it initiated development of physiological research, sometimes described today as *integrative physiology*. From this point of view, it was a certain milestone, which attempted at capturing the dynamics of relationships among the controls of circulation, kidneys, breathing, the volume and ionic composition of body fluids using a mathematical model, while applying a system view of physiological regulation. The Guyton’s diagram (Fig. 1) was reprinted many times in various publications (even in recent years). However, in spite of that, none of the authors reprinting the Guyton’s monumental diagram pointed out the fact that there were mistakes in the diagram. Provided that the classical Guyton’s model is implemented using current simulation tools and accurately according to

the graphic scheme, the model shall not work. However, such special tools were not available at the time this diagram was designed. The diagram was made only as a figure, the very program to implement the model was written by the authors in Fortran; however, the original source code is not available today.



*Figure 1: Extensive diagram of physiological circulatory regulations according to A. C. Guyton et al from 1972.*

As our aim was to apply the original classical Guyton's model in education of bioengineers, we had to correct the original diagram (Fig. 2). The correction required thorough revision of the entire model and system analysis of physiological regulations of the circulation system as well as numerous simulation experiments and their comparison with published results. A system of formalized physiological relationships expressed in the graphic form is the result; the system corresponds to the original model of Guyton et al [11] in its appearance but also behaviour. The model has been implemented as an interactive physiological diagram, making it possible, through simulation experiments, to understand better and deeper the physiological meaning of regulating bonds and their application in development of numerous pathophysiological conditions. We apply this diagram as an instruction teaching aid in education of physiological regulation systems for bioengineering specializations (Fig. 3).

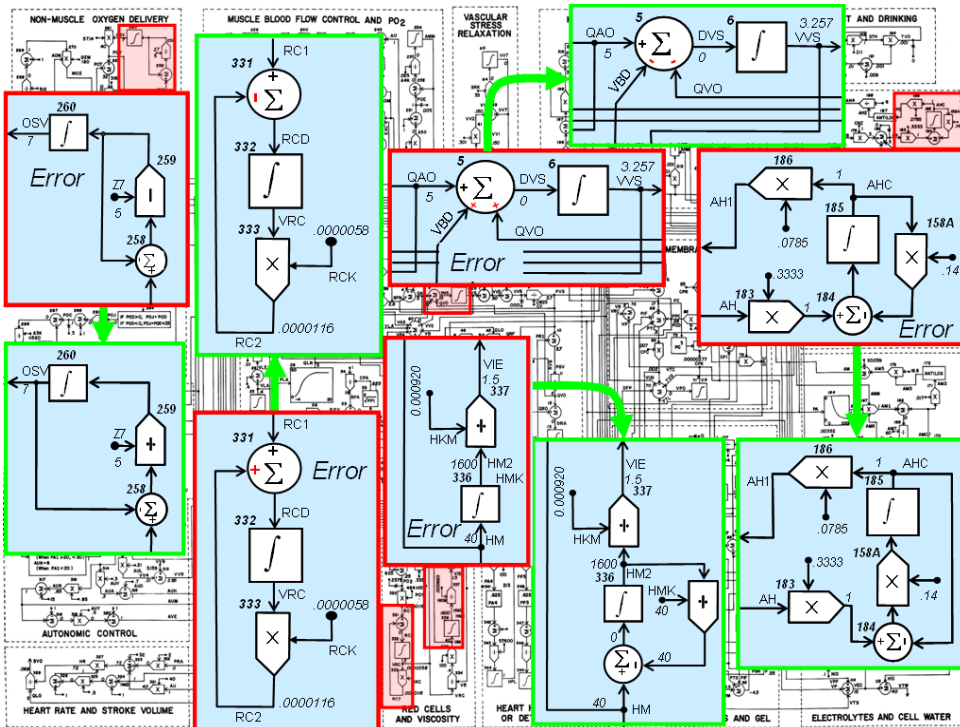
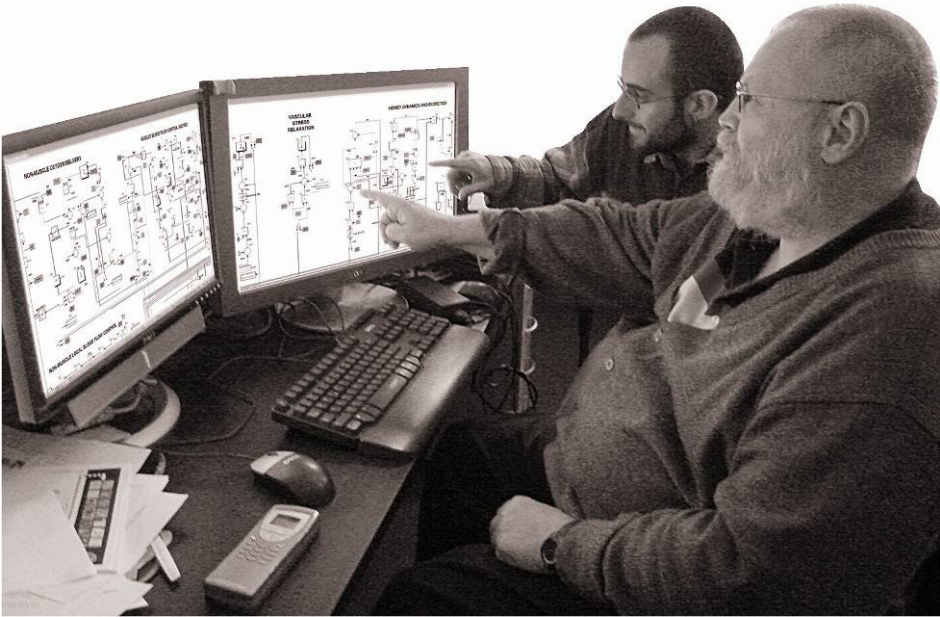


Figure 2: Corrections of the most significant errors in the graphic diagram of physiological circuit regulations according to A. C. Guyton et al.

However, the diagram is not very suitable for teaching of medical students – as they require simulators whose user interface looks more like interactive images of a physiological atlas than a control circuit diagram. Simulink implementation of the (corrected) Guyton’s model created by us is available for download at [www.physiome.cz/guyton](http://www.physiome.cz/guyton). Our Simulink implementation of a much more complex version of the Guyton et al model from later years is available at the same address, as well. At the same time, very detailed description of all mathematical relationships, together with reasoning, is provided on the website.

Guyton and his disciples continued constant further development of the model. In 1982, Thomas Coleman, Guyton’s disciple and collaborator, created the **model “Human”** intended especially for educational purposes. The model allowed for simulating numerous pathological conditions (cardiac and renal failure, haemorrhagic shock etc.), as well as the effect of some therapeutic interventions (infusion therapy, effect of some drugs, blood transfusion, artificial pulmonary ventilation, dialysis etc.) [4]. Recently, Meyers et al made the original Coleman’s model available on the web using Java implementation [13].



*Figure 3: Application of the physiological regulation model according to A. C. Guyton et al in education of bioengineers. However, the model is not quite suitable for medical education; an educational simulator should be designed for teaching of medical students, the user interface of which shall evoke images from medical textbooks and monographs rather than an interactive regulation diagram*

The *simulator Quantitative Human Physiology* is the most recent result of Guyton's disciples and followers, representing probably the most complex and extensive model of physiological functions at present times. The simulator is an extension of the original large circulatory system simulator (Quantitative Circulatory Physiology [1]) achieved by integrated connection of all important physiological systems. The model can be downloaded from the Internet [3].

We, too, created an *instruction simulator "Golem"* in the past, based on a complex model of integrated physiological regulations [8]. Our simulator "Golem" was focused on teaching of complex disorders of the internal environment [9].

## Internet Atlas of Physiology and Pathophysiology: Explanation Using Simulation Games

However, experience in application of complex models (of the Golem or QHP type mentioned above) in teaching shows that large and complex models are connected with a disadvantage from the didactic point of view, namely their complex control. The large number of input variables as well as the broad scale of options of observing the input variables require rather thorough understanding of the very structure of the simulation model on part of the user, as well as knowledge of what processes should be observed in simulations of certain pathological conditions. In the opposite case, a complex sophisticated model seems to the user only as a “complicated and not very understandable technical play” (similarly as if the user should face a complex airbus simulator without a prior theoretical instruction).

Instruction models (and apparently not only complex ones with hundreds of variables) in themselves therefore are not enough for efficient use in teaching. They must be accompanied by explanation of their application – using interactive educational applications at best. The possibility of using all advantages of virtual reality to explain complex pathophysiological processes arises only upon *establishing connection between explanation and simulation play*. In order to link the possibilities offered by interactive multimedia and simulation models in medical teaching, we have designed the concept of an Internet computer project, the *Atlas of Physiology and Pathophysiology* [10], conceived as a multimedia instruction aid that should help to explain, in a visual way using the Internet and simulation models, the function of individual physiological subsystems, the causes and manifestations of their disorders – see <http://physiome.cz/atlas>. The Atlas thus *combines explanation* (using an audio and animation) with *interactive simulation* play with physiological subsystems models, all available for free from the Internet.

## Simulation Models as “Live” Interactive Illustrations

The user interface of models used as the foundation for simulation plays rather evokes animated images from the printed Atlas of Physiology [15] or Atlas of Pathophysiology [16] than abstract regulation diagrams used in teaching of bioengineers (similar to those in Fig. 3). Unlike printed illustrations, however, images forming the user interface of multimedia simulators are “*live*” and *interactive* – changes of the *simulation model variables* are manifested by *changes of the images*. Using interactive illustrations thus conceived, it is possible to implement simulation plays which shall help to explain dynamic connexions in physiological systems, better than a static image or even a simple animation, and help especially to understand casual connexions in development of pathogeneses of varied diseases.

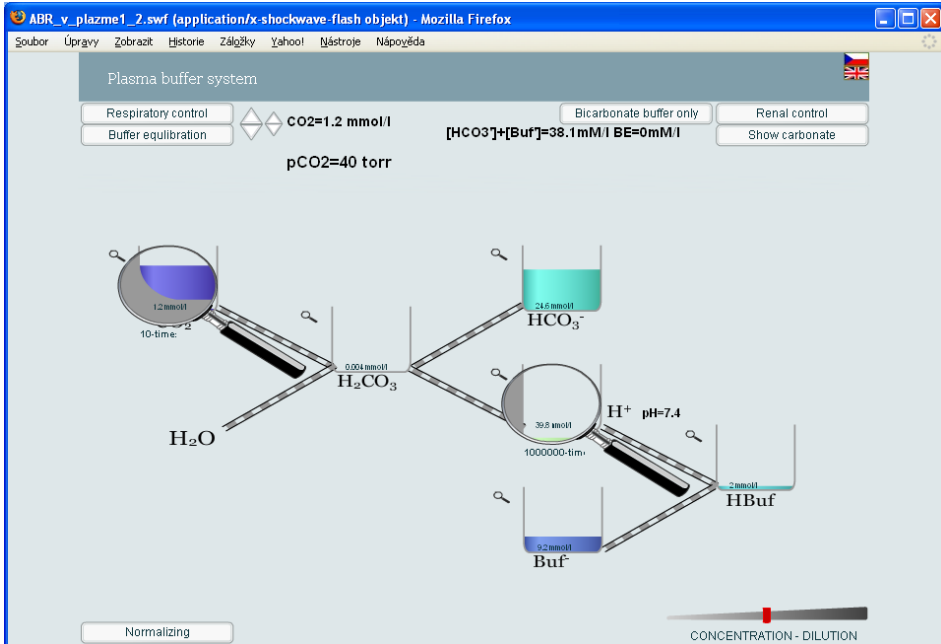


Figure 4a: Interactive educational model of the buffering plasma system. Fluid level values represent concentrations. Initial condition.

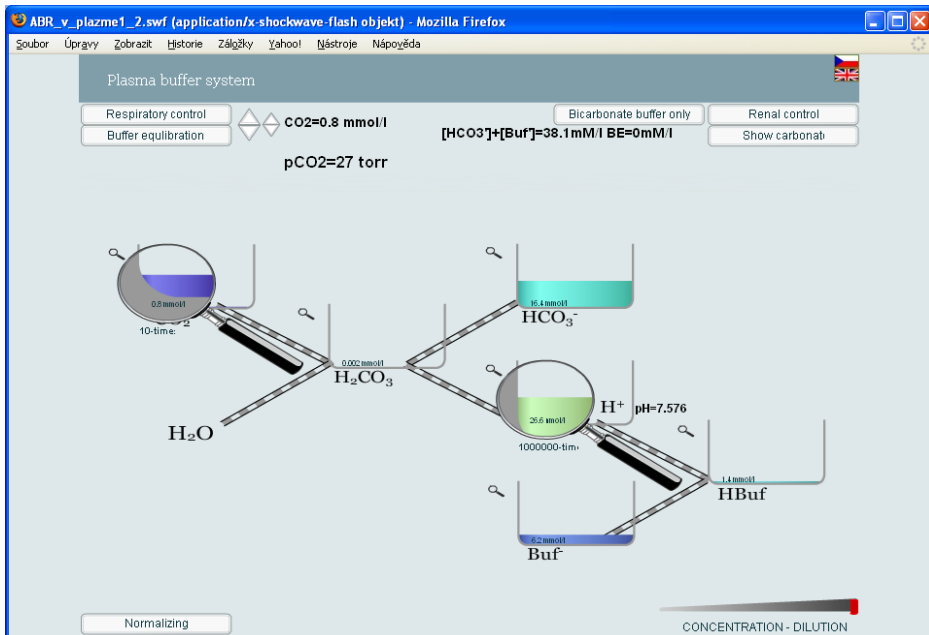


Figure 4b: Dilution can be invoked using the control slide; levels of all substances including  $\text{CO}_2$  concentration and hydrogen ions concentration shall become reduced.

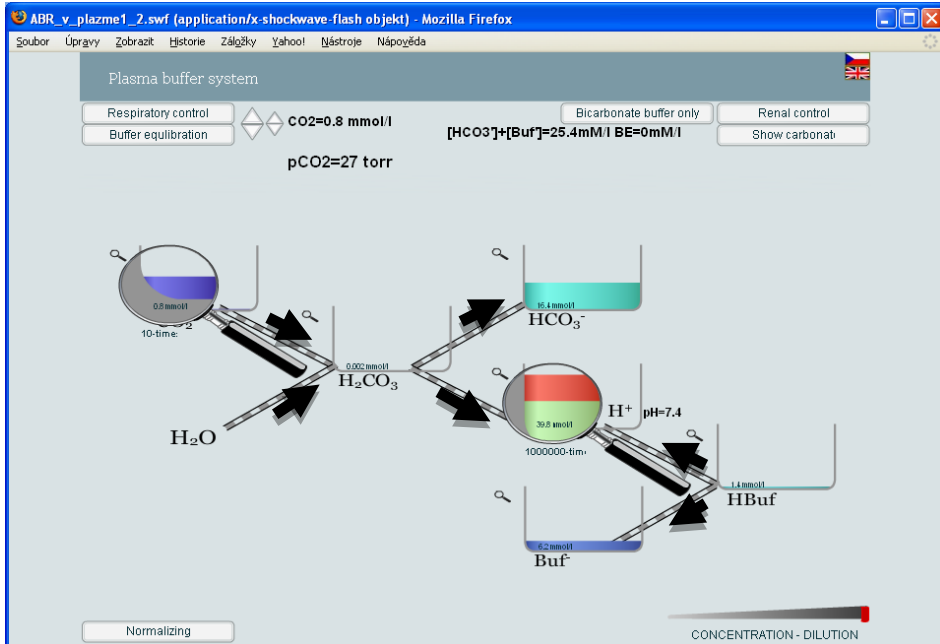


Figure 4c: Chemical equilibrium establishment in the buffering system can be engaged by pressing the button “Buffering Equilibration”; at the same time, plasma pH value returns to 7.4.

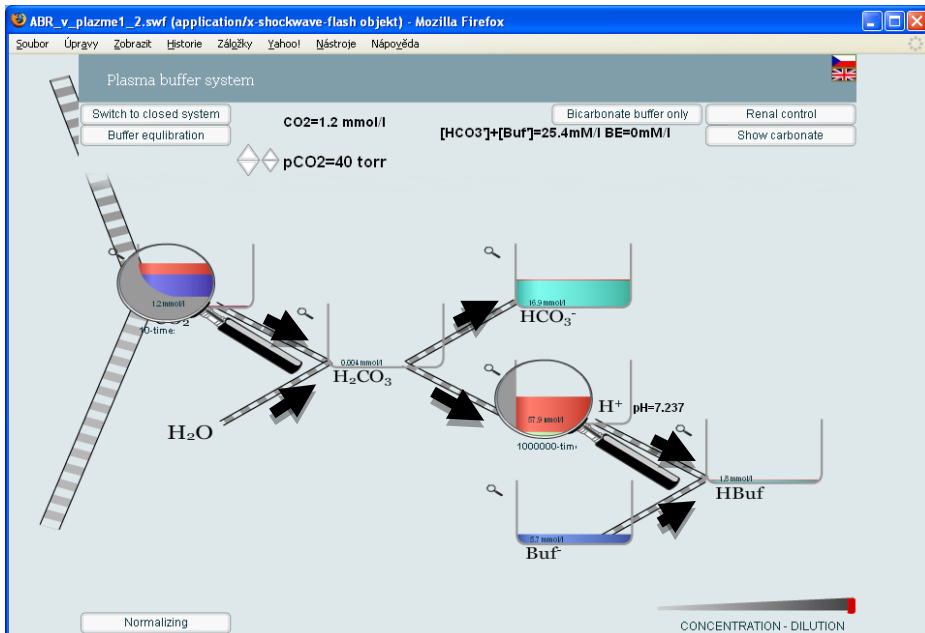


Figure 4d: Respiration increases (originally decreased upon dilution) the  $\text{CO}_2$  concentration value to the original level 1.2 mmol/L. Upon establishing new chemical equilibrium, hydrogen ions concentration increases and plasma pH value decreases.



The *model of acid-base equilibrium in plasma* can be mentioned as an example of a “pictorial” user interface in an instruction simulation play, where buffering systems in the user interface are shown as interconnected containers displaying compartments of individual substances. The model can be downloaded from: [http://www.physiome.cz/atlas/acidobaze/02/ABR\\_v\\_plazme1\\_2.swf](http://www.physiome.cz/atlas/acidobaze/02/ABR_v_plazme1_2.swf).

The “level” in these containers represents concentration. Chemical reactions are shown as “flows of liquid” among the containers with individual buffering system components. Substances from/into metabolism, respiratory system or kidneys can “flow in or out” of the containers. Using simulation plays with this models, the development of various acidobasic equilibrium disorders can be visually explained. Fig. 4a-d shows application of this simulator in a simulation play to explain *pathogenesis of dilution acidosis*. Dilution of individual buffer components is shown as expansion of appropriate containers – as the amount of components in the containers remains the same, the level (representing concentration) drops. The level of hydrogen ions drops as well (Fig. 4b). By pressing the button “buffering equilibration”, chemical reactions are started in the buffering systems, visualized as “flowing in/out” of individual components. Upon dissociation of carbonic acid and weak buffering acids (denoted as HBUF in the model – represented especially by albumin and phosphates in reality), the hydrogen ions level settles on the original value again (Fig. 4c). Nevertheless, the value of carbonic acid, just like the value of CO<sub>2</sub>, remains reduced due to dissociation. However, respiration in the organism maintains the CO<sub>2</sub> level in arterial blood on a constant level (given especially by the alveolar ventilation value). By pressing the button “respiratory regulation”, the CO<sub>2</sub> level increases back to its original value before dilution. By pressing the button “buffering equilibration”, a chemical reaction takes place, establishing a new chemical equilibrium with increased concentration of hydrogen ions (Fig. 4d).

### **The “Ceteris Paribus” Principle in Instruction Simulation Plays**

From the didactic point of view, it is always necessary to proceed from simple to more complex things in explanations. According to this principle, it is therefore suitable to use rather simple aggregated models (with few variables) during explanation, explain essential principles using these models, and then start making the model (and described physiological reality) more complex gradually. Instruction simulation plays forming part of the Atlas need not be always based on a highly complex model demanding from the calculation point of view with hundreds of variables – *even a simple interactive model can be a good helper in explaining pathogenic chains of development of various pathological conditions*.

From the didactic point of view, it is very efficient to ***disconnect regulation loops*** in the model at first and enable the students to ***study the responses of the selected physiological subsystem on changes of input variables*** in the simulation play (however, themselves regulated in a real organism). The dynamics of behaviour in gradual changes according to a single input are observed at first, while other inputs are set on a chosen constant value (the so called „*ceteris paribus*“ ***principle***).

This shall enable the students to ***understand better the meaning of individual regulation circuits*** and to study the effect (of disconnected and manually controlled at first) regulation bonds on behaviour of the organism in various pathological disorders and responses to relevant therapy. Based on our experience, it is precisely this approach that leads to better understanding of the meaning of individual regulation loops and understanding of their task in pathogenesis of various diseases, as well as understanding of pathophysiological principles of relevant therapeutic interventions.

Thus for example, it is not suitable to start with a simulation play with a model when explaining physiology and pathophysiology of circulation as its complexity is approximately on the same or higher level compared to the Guyton's circulation model mentioned in the introduction (see Fig. 1). It is more advisable to choose a simple aggregated model at the beginning, making it possible to demonstrate fundamental principles of the blood circulation structure and behaviour, as well as possibilities of its affection by means of regulation. The simplest ***circulation system model*** with ***disconnected regulation bonds*** as part of our Atlas is available at: <http://www.physiome.cz/atlas/cirkulace/05/SimpleUncontrolledSimulation.swf>.

Its control (see Fig. 5) is very easy and serves especially to clarify fundamental relationships among individual variables of the circulatory system (i.e. pressures and flows in the pulmonary and body circulation) and essential variables affecting the pressures and flows (however, themselves regulated in neurohumoral ways). They are as follows:

- Peripheral resistances (system and pulmonary);
- Pumping function of the right and left ventricle – implemented using the simplest way in the model, namely as inclination of the Starling curve (expressing dependence of the minute heart volume on filling pressures in the right and left atrium);
- Elasticity of arteries and veins (expressing pressure dependence on the vascular fill);
- Total volume of circulating blood.

The organism regulates the variables mentioned above (resistance is controlled by means of nervous and humoral regulation; myocardial frequency and inotropy modifies the shape of the Starling curve; venous tonus of large veins changes their elasticity; and the circulating blood volume is affected especially by renal activity, renin-angiotensin regulation etc.). However, these variables represent input (i.e. non-regulated) quantities in an aggregated model – the aim of the simulation play with the model is to obtain a clear notion of the meaning of these quantities for regulation of pressures, flows and distribution of the blood volume among individual parts of the bloodstream. Simulation play with this model makes it possible to explain the meaning of regulation of essential quantities of the circulatory system in pathogenesis of various circulatory system disorders to the students.

Figure 5 shows a *simulation play of development of right-sided circulatory failure*.

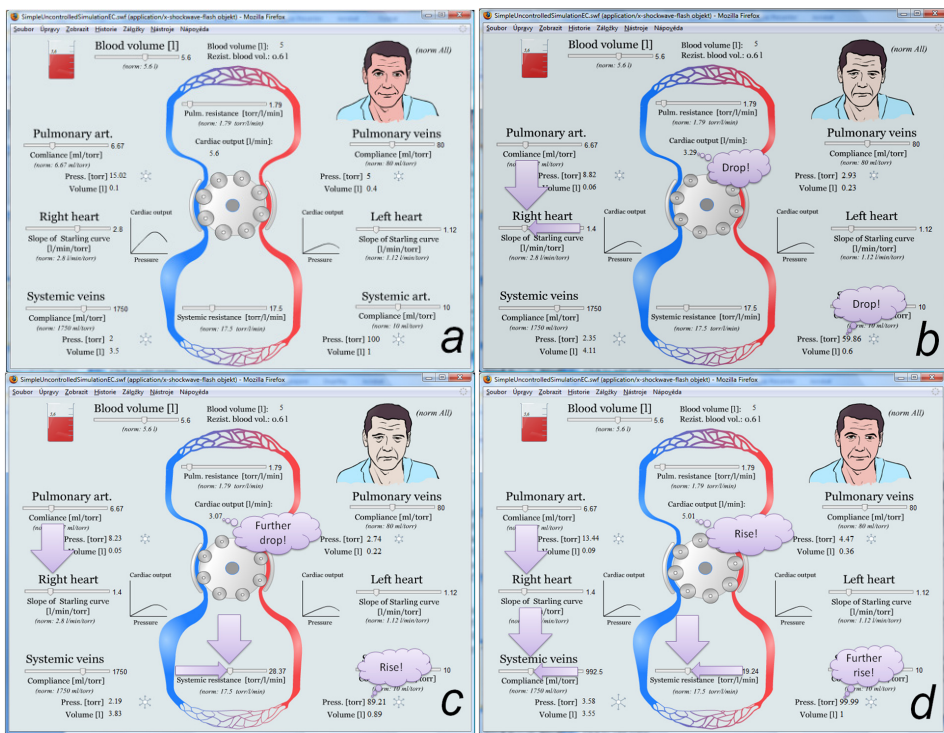


Figure 5: Use of a simple (non-controlled) circulatory system model to explain pathogenesis of right-sided circulation failure. See the text for more detailed explanation.

The procedure is to reduce the Starling curve inclination in the right heart using the slide at first – this models reduction of contractility of the right heart

upon acute right-sided circulatory failure (Fig. 5b). Minute heart volume drops to the value 3.29 L/min; mean system arterial pressure decreases to 59.56 Torr. Sympaticus responds to the blood pressure decrease by distinct vasoconstriction especially in the splanchnic region, in order to preserve perfusion of coronary blood vessels.

The next step is therefore to increase peripheral system resistance by moving the slide right (Fig. 5c) – mean arterial pressure increases to 89.21 Torr; however, minute heart volume drops further from 3.29 L/min to 3.07 L/min! However, sympaticus does not affect only vasoconstriction of arterioles and subsequent increase of peripheral resistance.

It also increases the tonus of large veins, which is manifested by increased pressure in them with the same blood fill – the venous tonus increase can be modelled by reduced elasticity of system veins (Fig. 5c). Reduced elasticity increases the pressure in large system veins and thus also the filling pressure in the right atrium, leading to increased minute heart volume (however, at the same time, the increase of venous pressure leads to higher filtration in capillaries and to oedemas). Mean arterial pressure increases to the normal value and it is not necessary to maintain the resistance value in the system bloodstream too high in order to preserve the pressure value – therefore the resistance should be reduced using the slide from 28.37 Torr/L/min to 19.24 Torr/L/min.

The simulation play can be continued further by demonstrating the meaning of the total blood volume increase, which occurs due to activation of the renin-angiotensin-aldosterone loop (not shown in the figure). Upon increasing the circulating blood volume using the slide, it can be shown in the model that peripheral resistance as well as venoconstriction can be reduced further (i.e. elasticity of large veins can be increased) in order to maintain normal minute heart volume and normal mean arterial pressure.

The simulation experiment can be furthermore used to demonstrate the effect of therapy, as well: Administration of cardiotonics can be illustrated by increasing the Starling curve inclination, and administration of diuretics can be simulated by reducing the increased circulating blood volume – pressure in large veins decreases as a consequence with subsequent reduction of oedemas.

It was our intention to illustrate using the example above how *simulation plays* with a model *shall contribute to better understanding of the meaning of individual regulation circuit application* in pathogenesis of various pathological conditions and in subsequent therapeutic interventions.

## **The Atlas as a Web-Based Application**

The Atlas of Physiology and Pathophysiology is currently designed as a web-based application that can be run in an Internet browser (a Flash player installed

in the browser is a prerequisite). Some simulation models require Microsoft .NET framework installed on the computer (if this part is not installed, its installation is offered before installing the first simulator, which requires .NET).

Explanatory chapters of the Atlas are designed as audio lectures accompanied by interactive multimedia images (see Fig. 6). Every animation is synchronized accurately with the explanatory text.

The Nanoengine for the ATP Production

Productivity: 100 molecules ATP/sec  
1 spin - 3 molecules ATP

Obsah	Miniaturo	Text	Vyhledat
Jméno snímku	Délka		
01_Introduction	00:28		
02_The Goals of the ...	00:53		
03_Nanogenerators in...	00:48		
04_The Fuel for Mitoc...	00:48		
05_The First Phase of ...	00:51		
06_The second Phase...	01:54		
07_The third Phase of...	01:40		
08_More Efficient than...	01:19		
09_Energetic Centre ...	01:16		
10_NADH and FADH2 ...	01:30		
11_Biological "Burnin...	02:26		
12_Electron Transport...	02:53		
12_Electron Transport...	00:23		
13_The Nanoengine f...	02:08		
14_Physiological Acco...	01:18		
15_The Supply of "Fu...	01:10		
16_Oxygen Supply a...	02:42		

Zbývá 6 minut 39 sekund

*Figure 6: Audio interactive lecture in the explanatory part of the Atlas of Physiology and Pathophysiology. Every explanation is accompanied by animated images synchronized with the explanatory part. Explanation can be stopped in any moment, to have a more detailed look at the accompanying animation. Explanation including the synchronized animations can also be moved backward using the slide in the bottom part of the player.*

However, the Internet-based Atlas of Physiology and Pathophysiology is much more than just an animated explanation with an audio track. The foundation of didactic efficiency is represented by **explanation accompanied by a simulation games**. Simulation models forming part of the Atlas are implemented as Flash applications and need not be installed separately (such as, for example, simulators in Figs. 4, 5 and 7) or (in more complex models) their separate installation is required directly from the Internet browser.

More complex models require somewhat more complicated control – a suitable scenario is therefore important, according to which the model can be used in the simulation play as an instruction aid to explain more complicated physiological relationships.

Some simulators combine the model as well as the explanatory part – *simulator of mechanical properties of muscles* (Fig. 7) can be mentioned as an example.

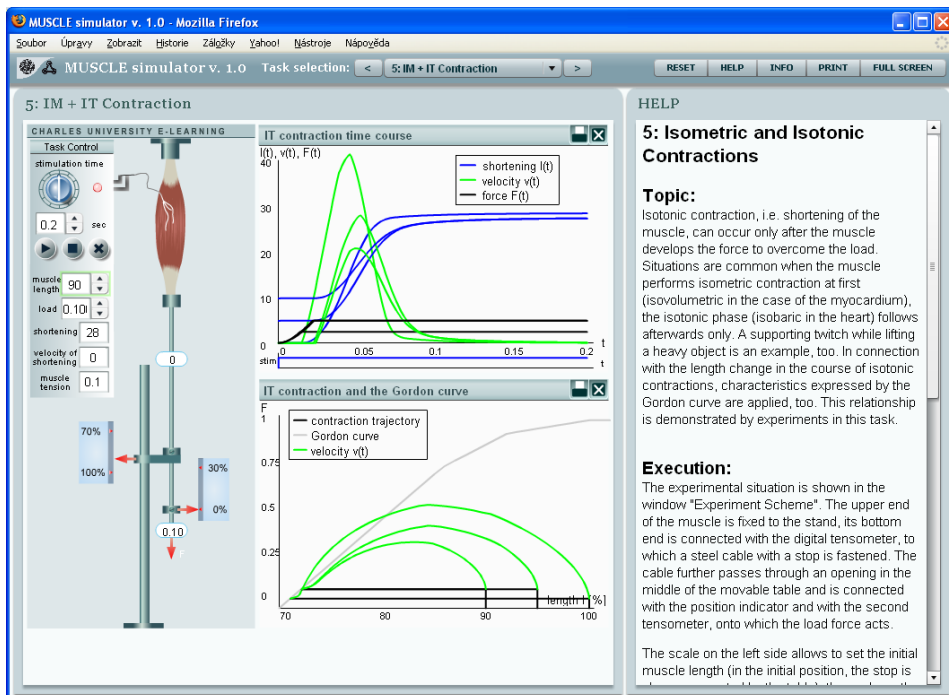


Figure 7: Simulator of the skeletal muscle mechanical properties is a Flash application designed as an explanatory chapter, which includes practical exercises with the model (accessible at <http://www.physiome.cz/atlas/sval/svalEN/SvalEN.html>)

Other simulators can be run separately and scenarios used in their control are designed as part of relevant explanatory chapters. The **complex model of blood gases transport** can be given as an example; this model shall be used as an instruction aid in explanation of physiology and pathophysiology of oxygen and carbon dioxide transport. Examples of using this simulator in explanation of consequences of ventilation-perfusion relationships disorders are shown in Figs. 8a-8e. The simulator can be downloaded from our Atlas using the link: <http://physiome.cz/atlas/sim/BloodyMary/>.

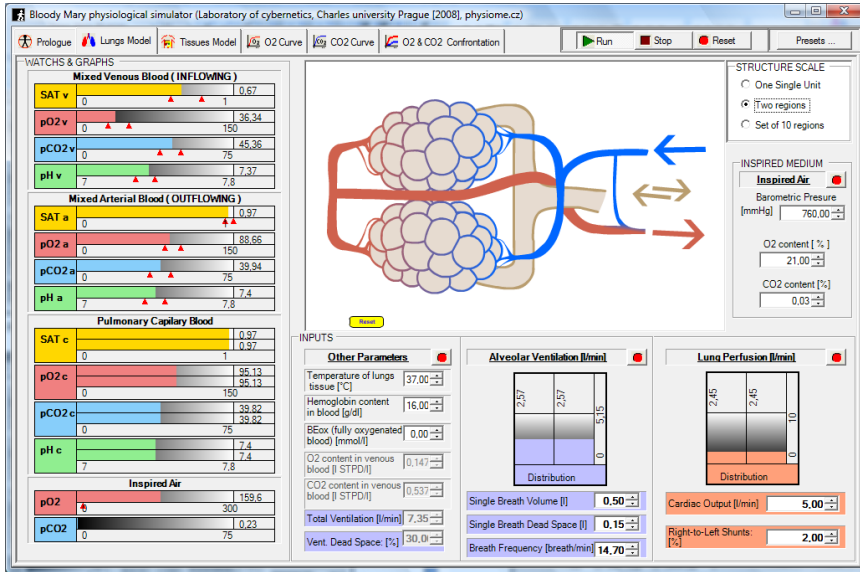


Figure 8a: Simulation play with the blood gases transport model to explain the consequences of ventilation – perfusion non-uniformity failures. Initial condition.

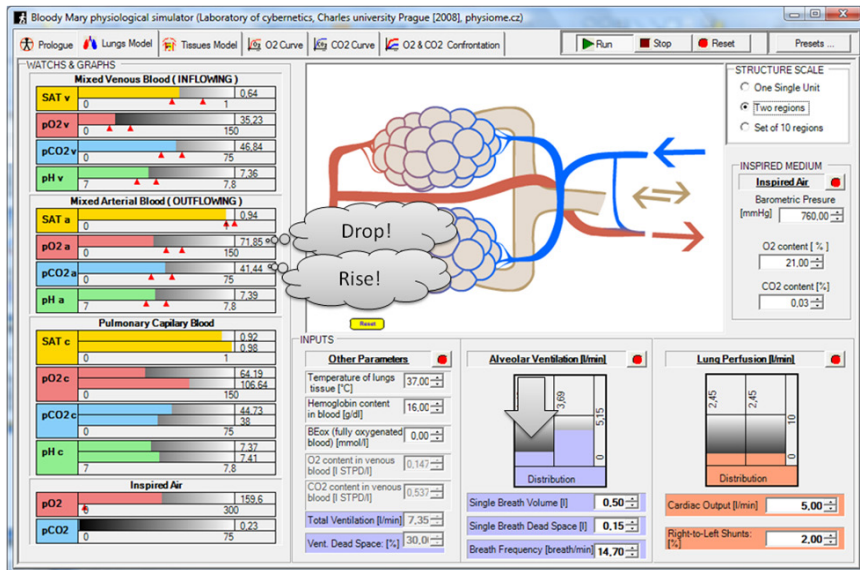


Figure 8b: Setting of different ventilation distribution shall cause decrease of PO2 and increase of pCO2 in mixed arterial blood.

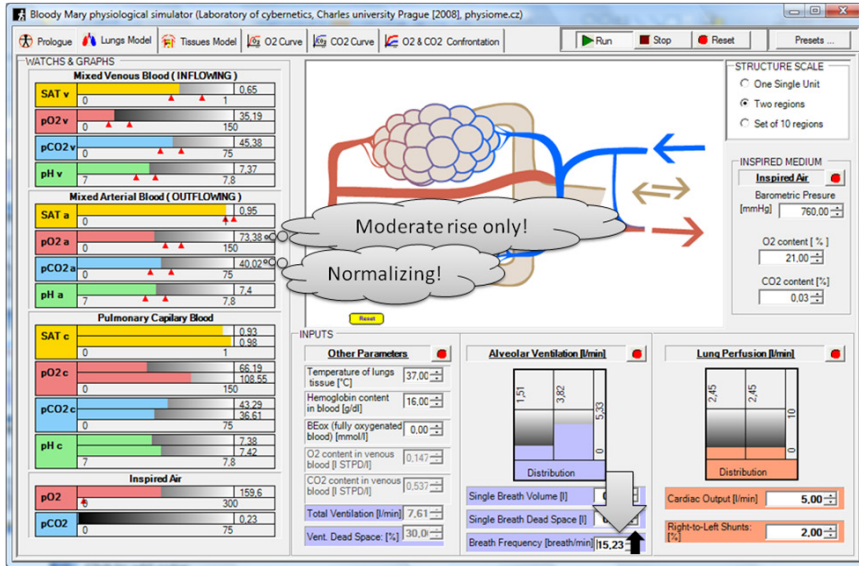


Figure 8c: Slight increase of the breath frequency means achievement of pCO2 normalization in mixed arterial blood; however, PO2 still remains low. Different shape of O2 and CO2 dissociation curves is the cause – see the following figure.

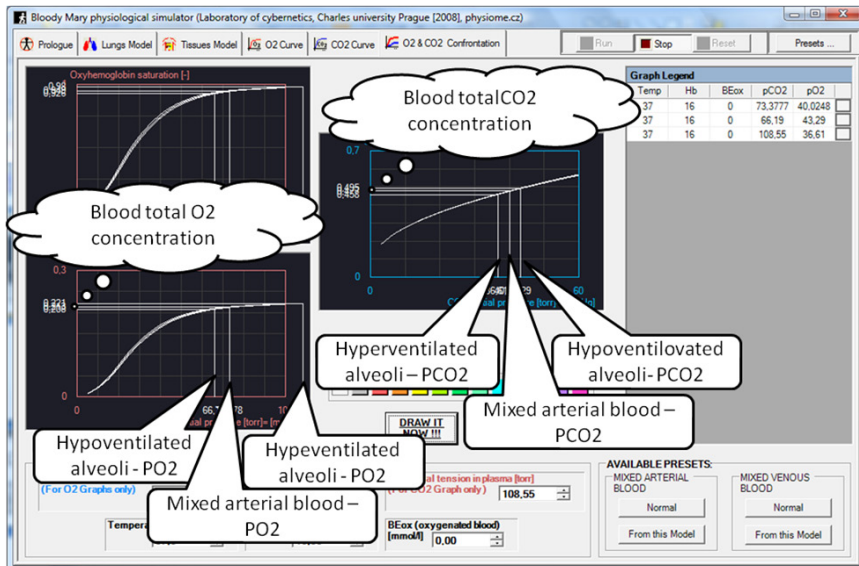


Figure 8d: Comparison of total concentrations and partial pressures O2 and CO2 in hyperventilated, hypoventilated alveoli and in mixed arterial blood.



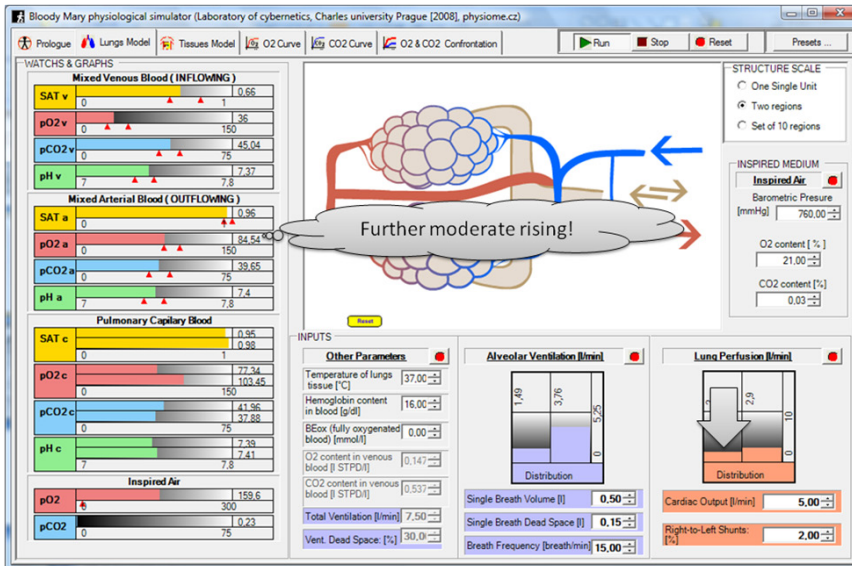


Figure 8e: Perfusion limitation by poorly ventilated alveoli limits admixing of hypooxygenated blood from hypoventilated alveoli, thus causing increased partial pressure of oxygen in mixed arterial blood. However, another consequence is also represented by increased resistance of the pulmonary bloodstream and development of precapillary pulmonary hypertension.

## Beyond the Atlas of Physiology and Pathophysiology Curtain – Creation Technology of Instruction Simulators

The creation process of the Atlas takes the form of a joint work made by *creative specialist's team encompassing various professions* (Fig. 9):

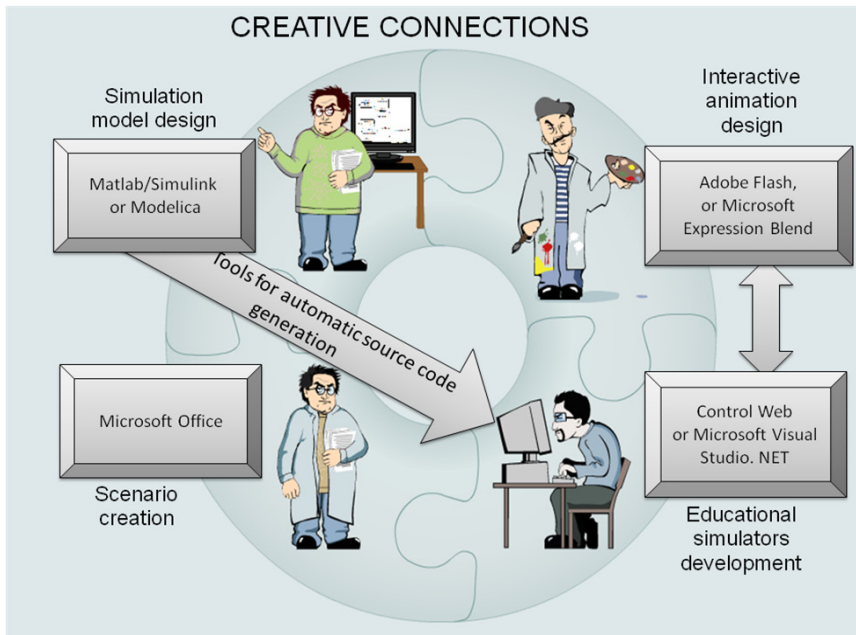
- Experienced teachers whose scenario is the foundation of a quality educational application;
- System analysts, responsible in cooperation with professionals of the given field, for designing simulation models for educational simulation plays;
- Artists designing the outside visual form;
- Computer science engineers (programmers) whose role is to “knit” the entire application into the resulting form.

For the interprofessional collective creation process described above to be efficient, each stage of the process should *utilize specific development tools*, with sufficient technical support, making it possible to apply component-based

creation of simulation models, interactive multimedia preparation, and their final interconnection pursuant to a given scenario into a compact unit.

Creative interconnection of various professions and development tools is therefore a prerequisite of success.

A multimedia presentation available from the Internet, found at <http://www.physiome.cz/atlas/info/01EN/index.htm> discusses the technologies used in the building process; methodology of creating educational simulators is described in [12].



*Figure 9: Atlas of Physiology and Pathophysiology is a joint work of a multidisciplinary team of pedagogues, system analyst, artists and computer scientists. In its process of creation, we strive to connect specialists of various professions as well as the development tools.*

## Foundation of an e-learning Educational Application – Scenario of Good Quality

The foundation of every explanatory chapter of the Atlas is represented by a quality *scenario*, designed by an experienced pedagogue. High attention must be paid to preparing the scenario. According to our experience, underestimating of thorough scenario preparation is paid for dearly by the necessity of unnecessary

iteration steps in development of the educational application and in subsequent extension of the development time.

The scenario must include a detailed proposal of assignment for the artist concerning the graphic appearance of every individual page, including animations, and the interactive behaviour proposal. The final graphic appearance is then up to the artist cooperating with the author of the given chapter. At the same time, the scenario must include key points of synchronizing the audio track with beginnings of individual animations.

When the explanation is accompanied by a simulation play (in the form of “training” using the simulation model), the *scenario according to which the students should manipulate with the model* must be thought over carefully so that the model behaviour clarifies those relationships, which are rather difficult to explain without a simulation play with the model (see the example of simulation plays application in Figs. 4, 5, 8).

## **Interactive Animations Built using the Threads of Simulation Models**

The making of *interactive animated images* (interconnected with explanations and simulation models) is frequently and wrongly underestimated – the truth is that precisely the graphic appearance of an educational application is frequently the aspect which “sells“ the e-learning product to potential users from the marketing point of view.

However, at the same time it should be noted that a professional artistic appearance of educational applications is demanding as for financial as well as human resources. Every image is an author’s work of art. The number of artists on the labour market who have mastered making of interactive computer animations is not really excessive. Moreover, thanks to development of Internet media, digital television, computer gaming industry and other information technology branches, the demand for these professionals on the labour market is rather increasing.

We tried to resolve the lack of interactive graphics professionals years ago already by establishing narrow working cooperation with Václav Hollar School of Fine Arts where we have built our external workplace – Interactive Graphics Laboratory. Our activities focused on training the teachers at first (and later students, as well) of the school in the field of using modern computer graphics tools, and thanks to our joint efforts we have created a new, three-year specialization “Interactive Graphics” at this school (at present, there are graduates from two year-classes already). We provide especially teaching of “Interactivity Mastering” specialization at the Václav Hollar College of Fine Arts, as well as guidance of the students’ practical experience. The students (and

also graduates today) of this college are those who provide the prevailing part of artistic appearance of our educational applications.

Until today, we have used especially Adobe products in designing interactive graphics – especially Adobe Flash and Adobe Flex. Lately we have started to turn to the Microsoft development environment, which offers very suitable tools allowing for good cooperation between programmers and artists – Microsoft Expression Blend (on part of the artists) and Visual Studio 2008 (with the WPF framework on part of the programmers) [7].

### **“Brain” of the Educational Simulator – Mathematical Model**

The core of the simulator consists in a mathematical model representing a formalized (mathematical) description of the physiological reality. Special development tools exist for development of mathematical models. In our laboratory, we have been using the environment Mathworks Matlab/Simulink on a long-term basis. We have developed a special library of formalized physiological relationships Physiology Blockset in Simulink, available for free on our website (<http://www.physiome.cz/simchips>).

Today, Mathworks development tools (Matlab and Simulink) rank among well-established industrial standards. As a rule, Simulink operates using connected blocks. Signals are transmitted through links between individual blocks; the signals serve to transfer values of individual variables from the output of one block to inputs of other blocks. Input information is processed in the blocks to output information. *Interconnection of blocks in Simulink* therefore reflects rather the *calculation procedure* than the very structure of the modelled reality. This is the so called *causal modelling*.

Recently, development of new, the so called “acausal” tools occurred, intended for making of simulation models. An essential innovation introduced by such tools consists in *declarative (thus acausal)* writing of models when *individual parts of the model are described directly as equations and not as an algorithm to solve the equations*.

These tools operate using interconnected components in which *equations* are defined. The equations do not express assignment (i.e. saving of the calculation result of an assigned statement into a given variable) but a definition of relationships among variables (as is the custom in mathematics and physics). These components (representing instances of classes with equations) can be connected through exactly defined interfaces – *connectors*. The important aspect is the fact that by connecting the components, *sets of equations in individual components become connected* with each other.

A typical representative of acausal modelling tools is the new object-oriented programming language **Modelica** [5]. Originally, it was developed in

Sweden and now is available both as an open-source version (developed under the auspices of the international organization Modelica Association, <http://www.modelica.org/>), and in two commercial implementations (Dymola of the company Dynasim AB and MathModelica of the company MathCore).

Mathworks, the producer of well-established Matlab/Simulink tools, responded to the new trends by designing a special Simulink library *Simscape* and related domain libraries SimElectronics, SimHydraulics, SimMechanics etc.

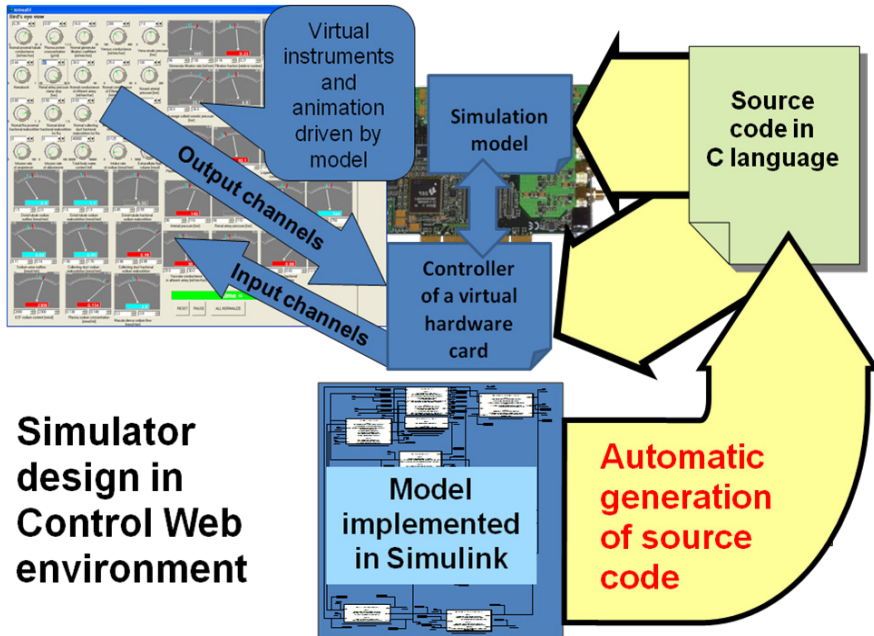
In accordance with modern trends, lately we have expanded the development tools used in making mathematical models (i.e. Matlab/Simulink) by tools *using the acausal modelling language – Modelica*. We are in the process of making our own development tool for this perspective modelling language, which shall make it possible *to generate the resulting model in the environment Microsoft .NET*, thus facilitating conversion of created and debugged models in the environment in which the very educational simulator shall be designed.

## Development of the Very Educational Simulator

Development of the educational simulator is demanding programming work, linked to the results of the mathematical model development and to the created elements of interactive graphics. In accordance with the designed scenario, graphic elements of the user interface must be “knitted” together with the mathematical model programmed in the background.

In the past, we have used the development environment *Control Web* to create simulators; this environment was originally designed to make industrial applications (control, management, control centres design) using a PC. Control Web provides numerous tools to create a complex user interface, allows for connecting Flash animations to the interface and to control it according to values of variables on the background. A Control Web application in its classical industrial deployment form communicates through a software controller of the hardware control and measurement card with the industrial technological device. Using the Control Web environment to create simulators, we have programmed a special software controller in whose core a simulation model is programmed. Control Web was thus “cheated”: It did not communicate with some industrial technology through the relevant software input/output channels but with a simulation model in the controller (see Fig. 10).

In order to facilitate development of “virtual measurement/control card” controllers containing a simulation model and not to have to write such a controller for each model “manually” in the C programming language, we have developed a special program that *enables us to generate the source text of the relevant virtual controller in C directly from a Simulink diagram*. This has



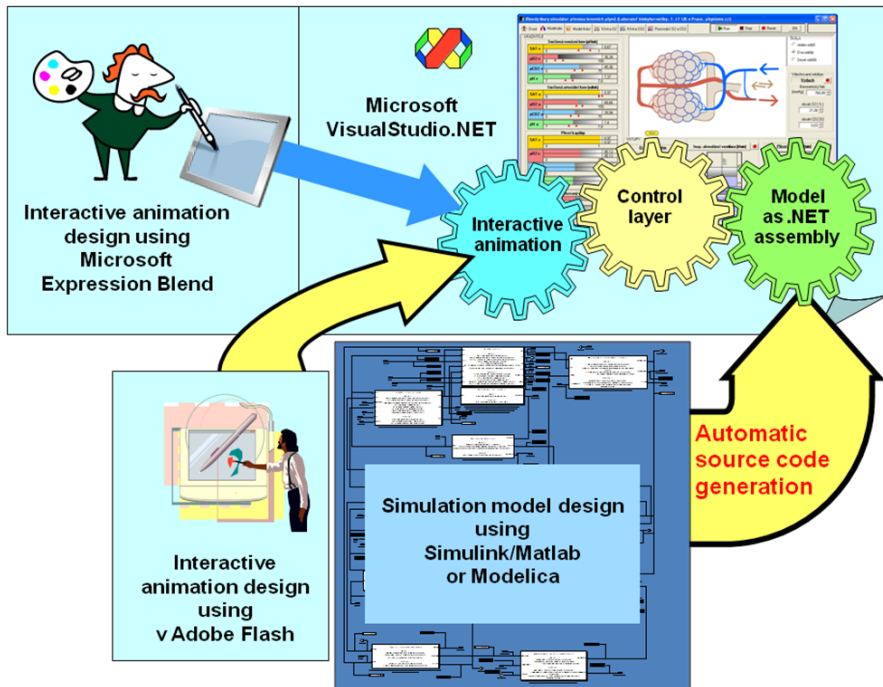
*Figure 10: Simulator development in the Control Web environment, originally designed for visualization of control and measurement industrial applications. The simulation model is programmed as a software controller of a (non-existent) virtual card, and the application under development in Control Web communicates with the model as if it was a technological device.*

allowed for simple and quick modification of the controller for Control Web upon making various adaptations and new versions of the simulation model.

For example, in Control Web we have created the simulator Golem [8] and as for the Atlas of Physiology and Pathophysiology, the kidneys simulator.

Currently, we are using classical programming tools to design the simulators. As far as simple Flash simulators are concerned, these are programmed directly in ActionScript, thus the programming language for Flash applications. As for the Atlas of Physiology and Pathophysiology, the simulator of mechanical properties of skeletal muscles is programmed in this language (see Fig. 7).

However, the ActionScript language development environment is not sufficient for more complex simulators. Therefore we use the Microsoft Visual Studio .NET programming environment in our laboratory, which, especially its latest version, provides extensive possibilities for programming work. In this environment, we are no more limited by “preset” elements of the user interface as is the case of Control Web, and moreover we can use all the power of a



*Figure 11: Making simulators in the .NET environment. The model is programmed as a component of the .NET environment (the so called .NET assembly) – preferably by means of automatic generation from models development tools (from the Matlab/Simulink or Modelica programming language environment). Graphic components are created in Adobe Flash or Microsoft Expression Blend. Creating animations in Expression Blend offers the advantage of creating both the animations as well as the simulator in the common .NET platform*

modern software application development tool; however, on the other hand, we must program ourselves many elements of the user interface for the application under development.

In order to make writing of the simulators easier (and not to have to program an already debugged simulation model “manually” in Visual Studio .NET), here, too, we have developed a special software tool [12] to automatically generate the simulation model from Simulink in the form of a component for the .NET environment (see Fig. 11).

To facilitate conversion of mathematical models from the Modelica language environment into .NET, we *are extending OpenModelica compiler* (as part of the international project *Open Modelica*) to *C# simulation code generation* (see Fig. 11).

Besides interconnection with the model creation tools, easy connection to graphic components of the user interface under development is important, as well. Flash components can be incorporated into the simulator in the process of creation through an Active X component.

The new .NET environment version also introduces entirely new possibilities of creating graphic components. Thanks to the new WPF (Windows Presentation Foundation) technology, complex graphic components can be created directly in the .NET platform, which include animations, vector graphics, 3D elements etc. (similarly as in Adobe Flash or even with potentially greater possibilities). It is important that the graphic user interface under development is directly integrated with the .NET platform, which removes the need of bridging the heterogeneous worlds of .NET and Adobe Flash in the simulators development.

Besides the above, the development tool to create graphic components (*Microsoft Expression Blend*) provides considerable support of cooperation of artists and programmers [13] thanks to the interface, which separates (and connects) the work of an artists and programmer. An artist can create complex animations in this tool very comfortably (using a graphic user interface), and the animations can be controlled easily. The programmer specifies such control by connecting to relevant program modules (the animations can be thus controlled by the simulation model on the background similarly as puppets on strings). Currently, we have trained artists in using this perspective tool.

Moreover, the new tool *Silverlight* shall make it possible to develop simulators, which can run directly in the Internet browser (even on computers with different operating systems – it is only necessary to install the relevant plugin in the browser).

New development tools of Microsoft provide a very perspective environment for development of simulators, and for the future, they represent our main development platform.

## Conclusion

Educational applications using simulation play, available through the web, represent a new educational aid, very efficient from the didactic point of view in explaining complex pathophysiological processes.

However, their process of creation is not very easy – it requires multidisciplinary team cooperation and use of suitable development tools.

*Their making is a combination of research and development work.* Research work consists in formalizing physiological reality by designing



mathematical models, while development work is the very creation of multimedia simulators, which make use of the mathematical models designed.

As our contribution to making modern e-learning tools which combine multimedia explanation with simulation plays, we have established the *Internet-based Atlas of Physiology and Pathophysiology project*.

The *Atlas project* is open-based – We shall make its results available in the Czech language for all those interested, and in the course of its development, we shall welcome cooperation with all who would like to take part in its gradual building process.

## References

- [1] Abram S. R., Hodnett, B. L., Summers R. L., Coleman T. G., Hester R.L., (2007), "Quantitative Circulatory Physiology: An Integrative Mathematical Model of Human Physiology for medical education.", *Advanced Physiology Education*, 31 (2), 202 – 210.
- [2] Burkhoff D. [2008, August] *The Heart Simulator*. [Online]. <http://www.columbia.edu/itc/hs/medical/heartsim/>
- [3] Coleman T. (2008, September). *Quantitative Human Physiology* [Online]. Available: <http://physiology.umc.edu/themodelingworkshop/> .
- [4] Coleman T. G. Randall J.E., (1983). "HUMAN. A comprehensive physiological model.", *The Physiologist*, vol. 26, (1): 15-21.
- [5] Fritzon P. (2003). *Principles of Object-Oriented Modeling and Simulation with Modelica 2.1*, ISBN 0-471-47163-1, Wiley-IEEE Press.
- [6] Guyton AC, Coleman TA, and Grander HJ. (1972). "Circulation: Overall Regulation." *Ann. Rev. Physiol.*, 41, p. 13-41.
- [7] Januszewski K., Rodrigues J. (2008 November) *The new iteration. How XAML transform the collaboration between designers and developers in window presentation foundation*. [Online] Available: <http://windowsclient.net/wpf/white-papers/thenewiteration.aspx>
- [8] Kofránek J. Anh Vu L. D., Snášelová H., Kerekeš R., Velan T., (2001). "GOLEM – Multimedia simulator for medical education." In Patel, L., Rogers, R., Haux R. (Eds.). *MEDINFO 2001, Proceedings of the 10th World Congress on Medical Informatics*. London: IOS Press, 1042-1046.
- [9] Kofránek J., Andrlík M, Kripner T and Matoušek S., (2005). "Biomedical Educations with Golem." In: *Interdisciplinary Aspects of Human-Machine Co-existence and Co-operation*, edited by Mařík V, Jacovkis P, Štěpánková O and Kléma J. Prague: Czech Technical University in Prague, 142-151.

- [10] Kofránek J., Matoušek S., Andrlík M., Stodulka P., Wünsch, Z., Privitzer P., Hlaváček J., Vacek O., (2007). "Atlas of physiology - internet simulation playground." In: *Proceedings of the 6th EUROSIM Congress on Modeling and Simulation*, Vol. 2. Full Papers (CD). (B. Zupanic, R. Karba, S. Blažič Eds.), University of Ljubljana, ISBN 978-3-901608-32-2, MO-2-P7-5, 1-9. The article is available at [http://patf-biokyb.lf1.cuni.cz/wiki/media/clanky/development\\_of\\_web\\_accessible\\_medical\\_simulators.pdf?id=wiki%3Auser%3Aseznam\\_publicaci&cache=cache](http://patf-biokyb.lf1.cuni.cz/wiki/media/clanky/development_of_web_accessible_medical_simulators.pdf?id=wiki%3Auser%3Aseznam_publicaci&cache=cache)
- [11] Kofránek J, Ruzs J., Matoušek S., (2007). "Guytons Diagram Brought to Life - from Graphic Chart to Simulation Model for Teaching Physiology." In *Technical Computing Prague 2007. 15th Annual Conference Proceedings. Full paper CD-ROM proceedings.* (P. Byron Ed.), Humusoft s.r.o. & Institute of Chemical Technology, Prague, ISBN 978-80-7080-658-6, 1-13, 2007. The article including source program codes is available at [http://dsp.vscht.cz/konference\\_matlab/MATLAB07/prispevky/kofranek\\_ruzs/kofranek\\_ruzs.pdf](http://dsp.vscht.cz/konference_matlab/MATLAB07/prispevky/kofranek_ruzs/kofranek_ruzs.pdf)
- [12] Kofránek J. (2008), "Design of Educational simulators, What is behind the curtain". (in Czech). In: *Mefanet report 01* Institut biostatistiky a analýz, Masarykova Univerzita. str. 60-72
- [13] Meyers R., Doherty C, Geoffrion L. (2008, September). *Web-Human Physiology Teaching Simulation (Physiology in Health, Disease and During Treatment)* [Online]. Available: <http://placid.skidmore.edu/human/index.php>
- [14] Oostendorp T. (2008,September). *ECGSim, version1.3* [Online]. Available: <http://www.ecgsim.org/>.
- [15] Silbernagl S., Despopoulos A. (2003). *Color Atlas of Physiology. 5th edition.* Georg Thieme VerlagThieme., New York, ISBN 9781604061147
- [16] Silbernagl, S., Lang, F. (2000) *Color Atlas of Pathophysiology.* Georg Thieme, New York, ISBN 9781604061444
- [17] University of Florida. (2008,September). *Virtual Anaesthesia Machine, Simulation Portfolio.* [Online] Available: <http://vam.anest.ufl.edu/simulations/simulationportfolio.php>

### Acknowledgements:

Development of the Atlas and educational simulation models takes place under the support of the MŠMT (Ministry of Education, Youth and Sports) grant 2C06031 – “e-Golem”, research MSM0021620806 and the company Creative Connections s.r.o.