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Using numeric simulation in an online e-learning environment to teach functional physiological contexts

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ABSTRACT

Background and objectives: Mathematical models are suitable to simulate complex biological processes by a set of non-linear differential equations. These simulation models can be used as an e-learning tool in medical education. However, in many cases these mathematical systems have to be treated numerically which is computationally intensive. The aim of the study was to develop a system for numerical simulation to be used in an online e-learning environment.

Methods: In the software system the simulation is located on the server as a CGI application. The user (student) selects the boundary conditions for the simulation (e.g., properties of a simulated patient) on the browser. With these parameters the simulation on the server is started and the simulation result is re-transferred to the browser.

Results: With this system two examples of e-learning units were realized. The first one uses a multi-compartment model of the glucose-insulin control loop for the simulation of the plasma glucose level after a simulated meal or during diabetes (including treatment by subcutaneous insulin application). The second one simulates the ion transport leading to the resting and action potential in nerves. The student can vary parameters systematically to explore the biological behavior of the system.

Conclusions: The described system is able to simulate complex biological processes and offers the possibility to use these models in an online e-learning environment. As far as the underlying principles can be described mathematically, this type of system can be applied to a broad spectrum of biomedical or natural scientific topics.

1. Introduction

With increasing capabilities of the internet Web-based e-learning becomes an interesting and promising tool for blended learning. E-learning can be used in preparation but also in post-processing of on-site courses. In many cases, however, these e-learning teaching units consist of texts, images or questionnaires and the student has only very limited possibilities to obtain a functional and quantitative understanding of

Abbreviations: LMS, learning management system.

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the biological mechanisms. Compared to practical course, in which the student can vary experimental conditions directly and observes the resulting changes, online e-learning systems often do not provide a direct cause–effect chain. However, in many basic subjects (e.g., physiology, biochemistry) but also in clinical therapeutic areas a quantitative understanding of causative relationships is essential.

Since many biological, chemical or physical processes can be described by mathematical formulas, one alternative to get an insight into complex biological behavior could be the use of numerical simulations. Typically described by a set of (differential) equations and empirical non-linearities the simulation calculates the temporal changes of observation parameters as a result of varying initial conditions. Mathematical modeling has been extensively used in biomedicine to describe numerous processes in the organism or during therapeutic interventions. Complex models exist for the description of the neural [1–3] or cardiac function [4], circulation and blood pressure control [5–7], on hormone regulation [8] but also for the immune system [9] or hemodialysis treatment [10]. These examples show the broad spectrum of applications for numerical modeling in biomedicine. Some of the models have been used to gain a deeper insight in the complex system interaction of various variables [6,11], others have been applied to optimize treatment strategies [12–14]. Since these models are suitable to simulate the complex behavior and interaction of body parameters, mathematical simulation is an appropriate tool to be used in an e-learning environment [15–17]. In these systems students can vary parameters systematically and observe the resulting quantitative effect on different system variables. Students can use these models either to get an insight in basic principles (e.g., blood pressure control in different time domains) but also to try treatment strategies with the help of simulated patients (e.g., insulin dosage for a diabetic patient).

Since the underlying mathematical models are rather complex in most cases, the requirements on the computational power are relatively high. Comprehensive simulation models used in education are therefore mostly realized as standalone applications used in a class room. But the use of simulation models could also be helpful in self-study at home. However, under these circumstances the use of standalone simulation applications needs the installation of executable software on the student's computer. Since students use different hardware and operating systems the software has to be developed for many systems. For this reason the use of Web-based simulation would allow students to work system independently on their own computer hardware or on tablet computers. However, the high computational demand is a major drawback for the use of complex models in an interactive Web-based e-learning environment. In general, sophisticated models are not applicable in a Web browser environment (e.g., using JavaScript). Therefore, the aim of the present project was to develop an approach of how the benefits of complex numerical simulation models can be used in an online e-learning environment. The concept is illustrated with two examples (simulation of the glucose-insulin control loop and diabetes therapy, generation of resting and action potential on excitable cells), but is applicable to a broad spectrum of topics in biomedicine.

2. Materials and methods

2.1. *Structure of Web-based simulation*

Many processes in natural sciences can be described mathematically for instance by differential equations. In simple cases one single or a limited number of differential equations can be solved in closed form resulting in relatively easy equations which can directly been used for example in a JavaScript program of a HTML page. However, in complex systems a large number of intricate differential equations which are closely interacting are necessary to describe the dynamic behavior. In many cases, especially in life sciences, non-linear functional relations, which have been identified only empirically, have to be included. These systems cannot be solved analytically but have to be assessed by numerical methods. These techniques are suitable to solve (approximately) an initial value problem and calculate the temporal change of system variables. However, these calculations require an extensive software (e.g., programing language APL) and are therefore much too complex to be performed in a JavaScript environment.

In our system any complex calculations are located on the Web server for instance as a CGI script application (Fig. 1). To initiate the computation for a specific set of boundary conditions the user (student), who works at his own client computer, enters these values in a suitable form within the Web browser. These data are sent to the server and the simulation is performed. The results, which mostly describe the temporal change of several system parameters, will be retransferred from the server to the browser either as a value list or as a graph and displayed to the student. The user can now vary the initial conditions and restart the simulation process to get an impression of the complex dynamic behavior. The interface for the user on the Web browser can be embedded in a teaching unit of an e-learning environment such ILIAS or MOODLE. Within this e-learning environment background knowledge of the biological process can be provided as well as an introduction of how to use the simulation. In addition, the logging of the results of systematic experiments can be managed in this teaching unit which could serve as a control for a successful work with the model.

In the following two examples will be described of how this structure can be used for complex e-learning units in life sciences.

2.2. *Example 1: glucose-insulin control loop*

Since glucose is an essential nutrient for the body, the stabilization of the blood glucose level under varying conditions (food intake, starvation) is indispensable. For this purpose the organism uses hormones in a strictly regulated control loop in which the actual glucose concentration is measured by the body resulting in an adequate release of the respective hormones. The most important hormone in this context is insulin which is released in the case of an elevated glucose level and which enables glucose uptake in many cells. The knowledge of this control loop is essential, since the widespread disease