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Towards General Developmental Curriculum "Fundamentals of Mathematical Engineering Modeling"

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An innovative general developmental curriculum is suggested for extra school training. It has been developed within the framework of the Russian Education Ministry assignment aimed at establishing nation-wide practice-oriented science and technology clubs for engineering creativity. Distinctive features of the curriculum are project-based learning and an emphasis on mathematical modeling in design and engineering. The purpose of the programme is to promote the engineering profession and education in the country, develop the bases for engineering thinking of a new type in upper form pupils. This type of thinking is required to solve the problems of the new generation associated with intelligent control, artificial intelligence and other issues commonly known as "Future Engineering".

Key words: engineering modeling, construction, future engineering, mathematical modeling, general enrichment educational programme.

Introduction

At the moment the specialists of engineering profiles with new research thinking are increasingly in demand in Russia. Simultaneously, due to penetration of engineering and technology in all spheres of human life, the problems solved by an engineer are continuously becoming more complicated. A modern specialist is required not only to know some information, but, first of all, be able to use it in solving non-standard problems, which have not been explicitly taught within the university study as they are cross-disciplinary.

For example, rapid research development of the 20th century in the sphere of artificial intellect resulted in a new type of problems requiring an engineer not only to have basic engineering education, but also profound mathematical training necessary to understand fundamentally new concepts, such as: intelligent control (for instance, in design problems of so-called "smart house"), possible issues of artificial intellect, software engineering, robotic technology, fuzzy intellectual systems, soft computing, bioinformatics, etc.

The training of such new type engineers should be started as early as at the school age. The first thing that should be taught for future engineers is bases of engineering modeling, since modeling and design are basic skills of any engineer that contribute to practical learning about the world, develop engineering thinking, stimulate for creative self-development, and, are, subsequently, a factor for professional advancement. In this condition, mathematical and closely connected with it computer modeling used for solving engineering problems have become one of the key components in engineering modeling.

Despite the growing demands of labour market for engineers of new generation, applicants still prefer to enter juridical, economic, and managerial departments. Therefore, one of the principle problems faced by the government today is to promote physics-mathematical, engineering and natural science education. This problem is also necessary to be solved as early as at the

school level at the time when schoolchildren develop their preferences in future job choice.

All these facts condition the urgency of developing additional general educational and developmental programmes [1-4] focused on pupils' involvement in engineering art, development of constructive thinking, and, as a consequence, motivation for future engineering job.

The current article describes the result of such work in the form of developmental curriculum "Bases of mathematical engineering modeling" for additional general education. The goal of the curriculum is to promote engineering jobs and engineering education in the country, decrease the graduates' withdrawal studying at engineering departments to other specialities, as well as senior pupils' acquisition of engineering thinking bases of new type, necessary for a contemporary engineer to solve the problems of new generation related to intellectual control, artificial intellect, and other issues of "future engineering".

The novelty of the curriculum consists in the fact that it relies on the issues of mathematical modeling: from the simplest questions of physical process modeling based on ordinary differential systems to the issues of complex process and phenomena modelling of stochastic and fuzzy nature using corresponding mathematical tools of possibility and probability theories, elements of intellectual control based on evolutionary algorithms, neural network, and fuzzy-logic controllers.

The curriculum content is adapted for senior pupils who have already got familiar with the bases of integral and differential calculation and have basic knowledge of algorithm development and programme writing in one of the structured programming languages.

The distinguishing feature is training based on one of the most common programming languages – Python which is free, simple to install and study, and keeping up with expressive power of modern languages such as C/C++, Java, C# and etc. Simple syntax and all basic data structures built in language allow more attention to practical study of the course theoretical concepts without much waste of time for tools.

One more feature is application of project-based technique that allows developing skills of team project work: pupils are divided into groups of 2-3, each group performs one of the suggested projects. At the end of the course the project results are presented for defense. All project tasks are divided according to the complexity level that enables to take into account children's age and individual characteristics.

Course content

The whole course is logically divided into four parts, each of which deals with definite modeling level whose complexity increases from part to part. The first part is the very first step in learning modeling, i.e. simulation of physical processes. These are the simplest and visual examples allowing pupils to understand what modeling is and why it is needed. The second part is concerned with traditional modeling of physical processes based on the simplest differential equations aimed at solution of practical problems. Mathematical tools used in this part are adapted for the school level: all models are built on the bases of ordinary differential equations of the first order which solutions are made by the Euler-Cauchy method. The third part considers modeling of more complicated processes which cannot be analytically described, and work on the "secret box" principle whose behavior can be evaluated only by some external signs of their functioning, where one needs to use simulation modeling. Finally, the fourth part is concerned with intellectual modeling of complex processes and phenomena, where the elements of artificial intellect (evolutionary algorithms, fuzzy systems, and soft computing) are used.

The course is structured into two parts. The former deals with engineering mathematical modeling, design, project-based approach itself. This part takes 36

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hours, within which pupils learn project-based technique performing simple projects in graph simulation of physical processes. In addition, pupils also learn to present the project results in the form of PP presentation at the end of the first half course.

The second part deals with the problems of engineering modeling (design), i.e. development of nontrivial systems based on modern intellectual methods enabling to solve small engineering problem. When performing the tasks of the second part the project-based technique is used. Pupils choose one of the suggested projects and work at it up to the course end. The results are presented for defense.

In the middle of the course there is an intermediate project defense, whereas the knowledge is monitored at the end of academic year in the form of final project defense. Both the former and the latter take place with result presentation in PowerPoint format.

Course content

We are presenting the components of curriculum and its content. The course takes 72 hours, 32 of which are intended for theory and 40 hours – for practice. The course is structured in such way that its practical part suggests both class and distant work (independent project work, learning material, teacher's consultations via e-mail or by means of other communication tools).

Unit 1. Introduction to engineering modeling (design) (2 h.)

Theory (2 h.): What is engineering? What is engineer? Types of engineering activity: 3D modeling, design, robotics, mathematical modeling, programming. Past, present and future of engineering, intellectual control, artificial intellect. Project-based technique. The project structure, its stages, project presentation. Elements of programming engineering in project-based technique. Entrance test to define pupil's level.

Unit 2. Introduction to Python programming language (10 h.)

Theory (6 h.): Computers and programming languages. Interpretation and compilation. Python Programming language. Design environment. Language syntax. Object-oriented and dependent-chance programming.

Practice (4 h.): Installation. Learning language and design environment. Python language syntax and key structures. Doing exercises. SimpleGUI user's interface design. Simplest geometrical drawing on a canvas.

Unit 3. Bases of mathematical modeling (2 h.)

Theory (2 h.): Mathematical model, principle stages. Direct and inverse problems of mathematical modeling. Genericity, analogue principle. Model hierarchy. Examples of modeling.

Unit 4. Visualization of simplest physical simulations (4 h.)

Theory (2 h.): SimpleGUI animation. Modeling of perfectly elastic collision of a ball with a surface and two balls collision in air-free environment.

Practice (2 h.): Programme design to visualize model.

Unit 5. Description and selection of study projects in graphic simulation of physical processes, project work (12 h.)

Theory (2 h.): Task description to perform study projects using the following models: (1) Brownian motion model: an option of dynamic control of particle diameter, initial temperature, potentials of cooling environment (momentum loss at collision with vessel), drawing of particle motion trajectory on a separate screen; (2) diffusion of two gases: dynamic control of gas density, gap width between vessels, gas temperature (particle velocity), diffusion coefficient calculation of both vessels on a separate screen; (3) pendulum model: non-convergent and convergent oscillations; (4) simulation of "Life" game with graphic visualization, development and study of different strategies. The project goal is to learn project-based technique, study and develop corresponding model, programme simulation and visualization, preparation and presentation of results.

Practice (10 h.): the pupils' group is divided into subgroups, each of which chooses a project. Before the middle of the course the subgroups develop their topics at the practical classes, at the end of the course there is a presentation of study projects. At the theory classes more complex modeling based on differential equations is studied. The subgroups finishing work before the deadline have a possibility to complicate their projects by adding dynamics described in differential equation.

Unit 6. Elements of computing mathematics (1 h.)

Theory (1 h.): The simplest ordinary differential equations (ODE). ODE systems. Numerical differentiation. The Euler-Cauchy method of ODE solution (ODE systems).

Unit 7. Free falling body (1 h.)

Theory (1 h.): Newton's second law. Free falling ball model in the air-free and viscous environment.

Unit 8. Motion of body thrown at an angle to the horizon (2h.)

Theory (2 h.): Motion model of a ball thrown at an angle to the horizon with and without environmental resistance.

Unit 9. Project presentation (2 h.)

Theory (2 h.): Presentation of study projects defending theoretical results in the PowerPoint format and practical results in the form of operating simulation. The review of project results.

Unit 10. Description and selection of final projects, project work (18 h.)

Theory (2 h.): Description of final project tasks using the following model: (1) development of computer visual system to recognize printed characters based on neuron networks; (2) optimization of оптимизация генетическим алгоритмом multi-criterion complicated function describing physical process; (3) simulation modeling of signal-controlled junction service system (calculation of optimal time to change a light at the junction depending on pedestrian traffic schedule and intensity); (4) the problem of increased complexity: building controllers of inverted pendulum; (5) the problem of increased complexity: building fuzzy controller based on neuron control network of transport stopping before obstacle. The project goal is to study and develop non-trivial system (Python programming) based on modern intellectual models and methods allowing solution of logically completed engineering problem.

Practice (16 h.): Pupils subgroups choose the projects and work at them up to the course end. The theoretical classes review different methods of complex process modeling with doing simplest demonstrational exercises.

Unit 11. Simulation modeling using the examples of service systems (4 h.)

Theory (2 h.): the key concepts of service system theory. Applications, building of probability distribution using frequency list, building of random-event generator using frequency list. Examples of service systems. Simulation modeling. The principles of simulation modeling system operation, multithreading, system object model, current software packages and libraries.

Practice (2 h.): Writing a programme to simulate modeling service system by the example of the simplest problem (the problem example: "Bus stop" – the task is to calculate the canopy square (in man-space) of a bus stop so that all passengers could keep the rain out at specified intensity of passengers' entrance and bus schedule independent of rain duration).

Unit 12. Genetic algorithms (4 h.)

Theory (2 h.): Evolutionary algorithms. Operation, origin, spheres of application. Structure of genetic algorithm. Advantages and disadvantages. Review of other intellectual optimization algorithms.

Practice (2 h.): Writing programmes to find optimal solution of the simplest problem of genetic algorithm optimizing. Solution process visualization.

Unit 13. Neuron networks (4 h.)

Theory (2 h.): Artificial neuron networks, their origin and development. Spheres of application. Class of problems. Study of networks with a teacher. One-layer perceptron for solving classification problems. Network learning. Existing programme packages and libraries of artificial neuron network modeling. Review of basic architectures of artificial neuron networks.

Practice (2 h.): Writing programmes to classify vectors by means of the simplest one-layer perceptron.

Unit 14. Fuzzy logical systems (4 h.)

Theory (2 h.): Elements of fuzzy set theory: fuzzy set, membership function, triangulated fuzzy numbers, α-level set. The systems of fuzzy inference. Field of application.

Practice (2 h.): Writing a programme to simulate the simplest system of fuzzy inference.

Unit 15. Presentation of final projects, review of results (2 h.)

Theory (2 h.): Presentation of project results with theory in PowerPoint format and practical results in the form of operating programme. Review of the course results.

Conclusion

The article suggests innovative general educational programmes for additional schoolchildren education, the distinguishing features of which are project-based technique and focus on mathematical modeling in engineering design. The work was performed in the frame of State Project of the RF Ministry of Education and Science to arrange and develop practice-oriented research clubs of engineering art. In curriculum development the representatives of Tver State University, Lobachevsky State University of Nizhniy Novgorod, Kazan National Research Technical University named after A. N. Tupolev and Ogarev Mordovia State University took part, it was presented at the seminars held in Moscow and Saint-Petersburg.

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Perspectives of Smart System Math-Bridge for Learning Array Sorting Methods

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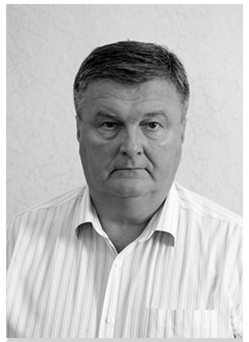

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The article proposes the use of Math-Bridge smart system as a tool to train and control knowledge of engineering students in the methods of sorting arrays.

Key words: Math-Bridge, sorting, exercise, direct exchange, algorithm.

Application of training systems is one of the most advanced ways for educational information technology development. A training smart system Math-Bridge is a significant break-through made in this direction. It allows working with a wide scope of dynamic objects converted from usual graphic objects by means of a special editor [1]. A theoretical base for such systems was developed by Skinner B.F. and Crowder N.A. in the 1950-s of the 20th century. These systems are to take into account not only correct answers but also the ways that lead to the solutions [2]. Thus, the smart systems that provide a wide range of diverse objects and ready templates as tools are of special interest. The system is known to have been developed to train engineering students and students of natural science profile in the frame of MetaMath project [3, 4]. The course "Algebra and geometry" was developed in the frame of the project [5]. However, as practice shows, Math-Bridge toolkit can be successfully applied while training students from other majors [6].

This article studies the ways to use the system Math-Bridge to train and control the students of "Information and computer science" major on array sorting methods provided within the course "Algorithm and data structures". Specific features of creating dynamic training objects are used in this case [7]. Let us choose an Exercise as an object (fig. 1). This object can be directly used by making training algorithm via Educational material editor (fig. 1), or it is possible to choose one of the following (fig. 1, 2).

This approach is one of the easiest and fastest ways to create training and testing elements. The system includes six standard templates that allow designing exercises with one or two interactions with a trainee. The template types for exercise design are shown in fig. 2.

Besides, there is an opportunity to design dynamic objects by means of separate units, which allows implementing multi-level algorithms for further development of complex educational algorithms applied

Fig. 1. Dynamic objects and educational material editor