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DIDACTIC POSSIBILITIES OF USE OF THE VISCOUS-ELASTIC BODY SIMULATION IN PEDAGOGICAL UNIVERSITY

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Abstract:
The article discusses the didactic possibilities of body motion modeling by replacing it with the particles system connected by weightless viscous-elastic rods. It is shown that such computer models allow: 1) to study translational, rotational motion, bodies deformation, precession of gyroscope, etc., to actualize the knowledge of the corresponding concepts and laws of mechanics; 2) to intensify the educational and cognitive students' activity, to increase their motivation for learning; 3) to master the computer modeling method, to explain the algorithms used and the simulation results; 4) to develop physical and algorithmic thinking, the ability of the coordinate method application, to carry out mathematical processing of information; 5) to implement an interactive dialogue between the student and the computer program; 6) to visualize information about the state of the object, to build motion graphics; 7) to create various animations of the body motion and deformation; 8) to create problem situations that require editing a computer program; 9) to deepen interdisciplinary connections between mathematics, physics and computer science.
Key words: *activity, didactics, education, modeling, motivation, training.*

Introduction

A graduate of the pedagogical high school must possess cognitive, informational, research, mathematical, creative and other competencies. The development of the informatics, physics and mathematics teachers' professional competencies during the computer modeling classes in a pedagogical university requires the formation of the ability to create simple computer programs, which simulate various physical, biological, socio-economic and other systems and phenomena. All this presupposes the provision of conscious and independence of learning, the educational activities intensification, which can be achieved by solving the professional orientation tasks, and will allow to move from simple reproduction of the studied material to the solution of creative problems. In this connection, the problem of creation and development of the non-complex tasks collection on computer modeling of various systems is urgent. The computer models application promotes the establishment of interdisciplinary links between mathematics, physics, computer science. They can be used in educational research, in course and diploma works, as well as for simulations of the real world physical laws in computer games. In this case, the educational activities grow is ensured by: 1) the selection of knowledge-intensive computer models and the corresponding tasks; 2) the variability of actions at work with computer models and carrying out computational experiment; 3) the stimulation of mental activity by questions and estimates.

The article purpose is to identify the didactic possibilities of modeling the body motion by replacing it with the material points system, interconnected by visco-elastic rods, in the class for computer modeling at the pedagogical university. The research hypothesis is as follows: the body modeling by a system of particles connected by weightless visco-elastic rods, obeying the basic law of dynamics, really allows: 1) to obtain computer animation, i.e. visual image of the moving body at subsequent moments of time; 2) to build the dependency graphs of points coordinates, velocities and accelerations on time; 3) to simulate the translational, rotational, flat and spherical body movement, the body interaction with the surface or another body, to study precession gyroscope and other phenomena; 4) to grow the student's mental activity, increase their motivation to learn. The methodological basis of research are works by V.I. Zagvjazinskij [1], I. A. Zimnjaja [2], V.M. Krol' [3], I.V. Robert [4], M.A. Holodnaja [5] (basics of didactics), and L. A. Bulavin, N.V. Vygornickij, N.I. Lebovka [6], H. Guld, Ja. Tobochnik [7], S. Kunin [8], S. E. Popov [9], V.I. Rashhikov, A.S. Roshal' [10], V.A. Saranin [11], N.D. Ugrinovich [12], N.J. Giordano [13], M.M. Woolfson, G.J. Pert [14] (physical phenomena simulation). We used a computer program in Pascal (Free Pascal IDE, ABC-Pascal). This programming language is specially created for education, it is studied in school, therefore students of pedagogical institutions are interested in learning it.

Discussion

Training is effective only when students have a high motivation and personal interest in its results, aware the usefulness of the acquired knowledge and skills. To create motivation for educational activities, it is necessary to form cognitive interest to the studied issues; for this purpose it is need to solve professionally oriented tasks, closely connected with courses of mathematics, physics and informatics. In computer modeling classes, you can create different models of physical, biological, socio-economic, and other systems. Let's limit ourselves to consideration of two-dimensional and three-dimensional models of the solid and visco-elastic body motion, in which the linked particles method is used.

The essence of the discussed method is as follows. The simulated body is replaced by a system of material points interconnected by visco-elastic rods, each of which consists of elastic and dissipative elements connected in parallel. At the initial moment of time, when the body is not deformed, the program calculates the distances $s_{i,j}$ between the pairs of particles spaced at distance that does not exceed the radius of forces action $R_{\max}$. During the body deformation j-th particle shifts relatively i-th, this leads to the appearance of an "elastic" force and the viscous friction force. By changing the value $R_{\max}$, the coefficients of elasticity k and viscosity r, it is possible to simulate a visco-elastic body with different properties. If the body is in the gravitational field, the gravity forces acting on each material point are taken into account. The cycle sequentially considers all the particles and the acceleration projections are calculated for each particle using the basic dynamics laws. For calculation of speeds and coordinates is applied Euler's method [6, 12]. Then the result is displayed, the variable τ is incremented by $\Delta\tau$, and everything is repeated again.

The method under discussion allows one to simulate the motion and deformation of extended bodies. The force of the "elastic" interaction $F_{i,j}^{el}$ between any two particles of the body is equal to: 1) $F_{\max}$, if $l_{i,j} < R_{\min}$; 2) $k(s_{i,j} - l_{i,j})$, if $R_{\min} \le l_{i,j} \le R_{\max}$; 3) zero, if $l_{i,j} > R_{\max}$. Here $l_{i,j}$ is the distance between i-th and j-th particles at given time moment. The viscous friction force is proportional to the velocity of the relative motion of the particles $(F_v = r\Delta l_{i,j} / \Delta\tau)$. If the stiffness k of the links is small, then the body is elastic and easily changes its size and shape. With large k body is solid, poorly deformed. If the forces action radius $R_{\max}$ is small, the body with small deformations is destroyed, i.e. body is fragile. If the particles are displaced relative to each other over long distances, breaking the old and forming new links with other particles, the body is viscous, it experiences the plastic deformation.

The use of mathematical abstractions, algorithms of branching and cyclic structure, elements of computer graphics promotes the development of theoretical, algorithmic and visual-figurative thinking. Automation of calculations, the possibility of loop creation allows to perform laborious mathematical the calculations quickly, to obtain and examine the dependency graphs, which are experimentally difficult to study. The combination of logical and mathematical processing of information with model visibility leads to the activation of memory, attention, observation and the student's intellectual potential development. As an example of the application of the linked particles method, we consider several tasks which require the calculation of the movement and deformation of the body.

1. The problem of collision of the visco-elastic body with solid surface. The inelastic body of a rectangular shape participates in planar motion so that all its particles move parallel to the vertical plane. The mass center moves along a parabola, the body itself rotates. The body collides with the vertical or horizontal surface. It is necessary to model the body movement, to obtain the trajectories of its particles.

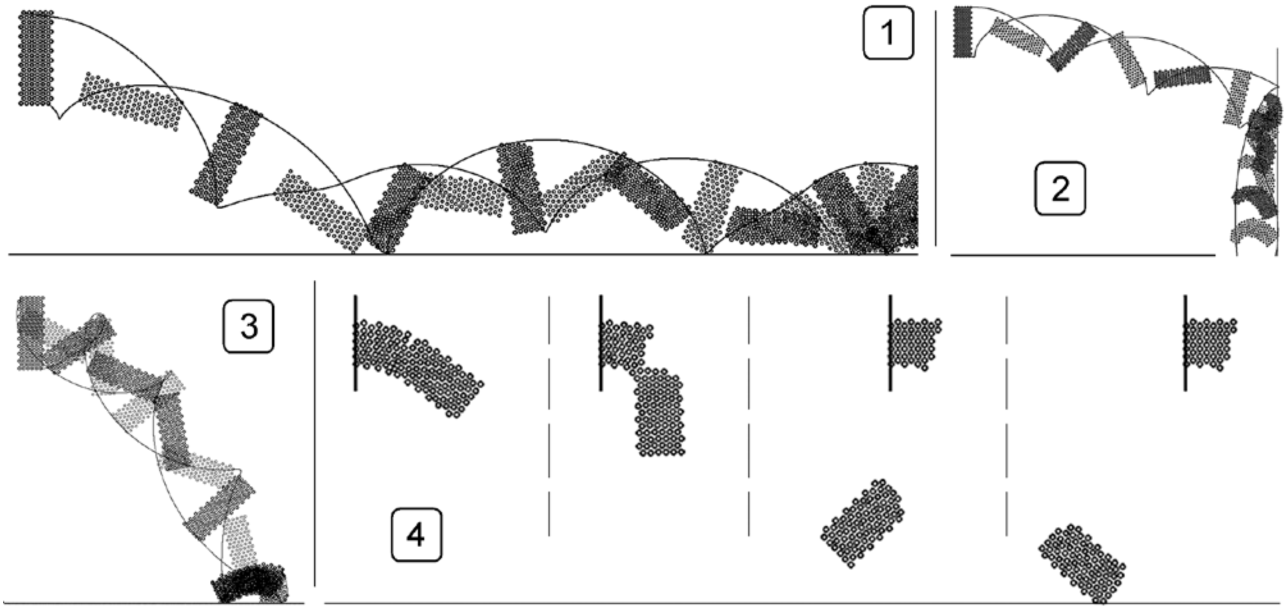

Fig. 1. The collision of the body with the surface and the beam destruction.

In the present case $R_{\min} = 6$, $R_{\max} = 10$, $b = 8$, $k = 10^3$, $r_s = 25 \cdot 10^4$. That is, at large distances ($l_{i,j} > R_{\max}$) particles do not interact, and with strong rapproachement a large repulsion force arises $(F_{\max} = 10^4)$. If the particles are at the right hexagon vertices (hexagonal lattice), then at given force $F_{i,j}^{el}$ each of particles interacts with six neighboring ones. When the body is not deformed, the system is in equilibrium, the distance $l_{i,j}$ between the particles is equal $s_{i,j}$, the "elasticity" force $F_{i,j}^{el} = 0$. If the particle collides with the surface, then the reaction force begins to act on it. The component of the particle velocity, which is perpendicular to a surface, decreases by 1.2–1.4 times and changes its direction to the opposite.

The simulation results are shown in Fig. 1.1–1.3. The program allows to create computer animation of the moving body colliding with the surface, to calculate the trajectory of any particle, to display on the screen the projection of speed and acceleration at any time.

2. The problem of the beam with a defect. The left end of the horizontal beam is fixed and the load is attached to the right end. The central part of the beam has defects and is destroyed at low loads. It is need to model the beam deformation, the destruction and movement of its parts. All points of the beam are moved parallel to the vertical plane.

The beam is represented as a set of spherical particles located in the vertical plane and linked by weightless visco-elastic rods ($k = 10^3$, $r = 5 \cdot 10^4$). If the distance between the particles exceeds $R_{\max}$, the connections are destroyed without the possibility of recovery. In the middle part of the beam there is a defect; for the particles located there, the elasticity coefficient of the links is 3 times less (k not 10^3, but 300). The right end of the beam is additionally loaded, so it bends strongly in the central part and breaks off. The simulation results are shown in Fig. 1.4. It can be seen that at given system parameters, the severed part of the beam falls to the ground and turns out to be to the left of its fixing point.

3. The problem of the two bodies collision. The projectile strikes fixed target, partially elastic interaction takes place. The projectile and targets masses are known. Simulate this phenomenon, calculate the movement of bodies.

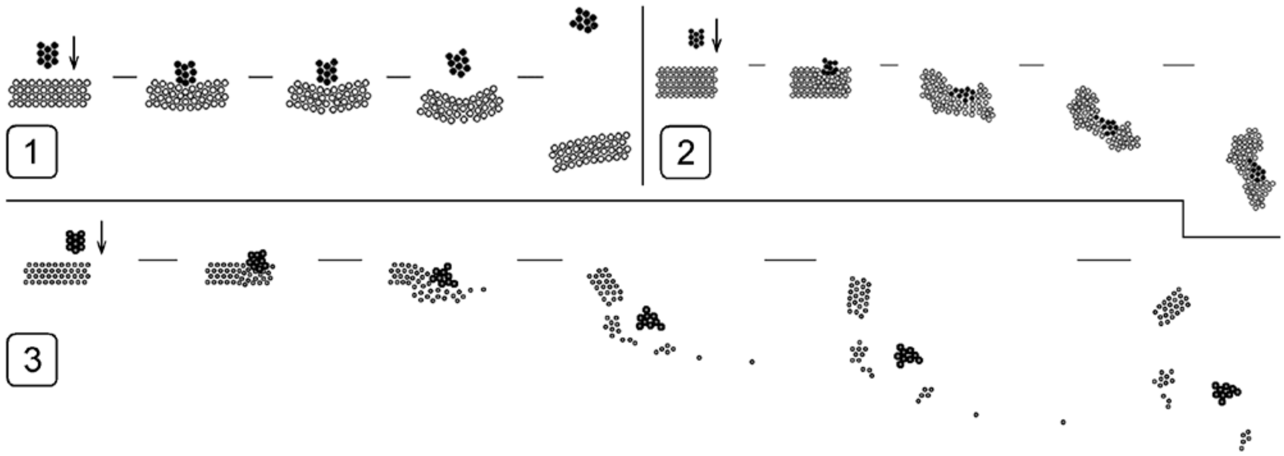

Fig. 2. The simulation results of the collision of the projectile with the target.

The projectile is modeled by 9 particles, the target by 50 particles. In order to simulate an absolutely inelastic impact, it is necessary: 1) to reduce the coefficients k and r; 2) to make the model take into account the occurrence of attractive forces arising when the projectile particles approach the target. In this case, after the interaction of bodies, the projectile and the target "stick together" and move as a whole, rotating in accordance with the law of momentum conservation. Fig. 4 shows the following situations: 1) the projectile collides with the target partially elastically and flies away from it, the interacting bodies restore their shape (Fig. 4.1); 2) interaction of the projectile and target completely inelastic, after the impact the body move together (Fig. 4.2); 3) the projectile destroys the target, the bodies fragments, rotating, fly in different directions (Fig. 4.3).

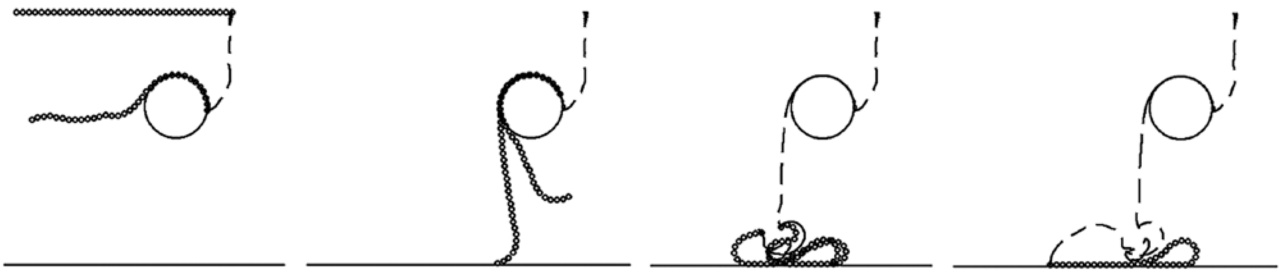

Fig. 3. The fall of the chain on the horizontal cylinder.

4. The problem of the chain falling on the cylinder. The long chain falls on the horizontally located cylinder, and then slides off onto the horizontal surface of the table. It is necessary to calculate the coordinates and velocities of various points of the chain at subsequent time moments, to construct the trajectory of one of its points, to create a computer animation.

To simulate the chain movement, it is sufficient to consider one row of particles, each particle interacting with only two particles on the left and two particles on the right ($R_{\max} = 18$, $s_{i,j} = 8$). The initial state of the system must be set correctly. In all other respects the task is solved in

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exactly the same way. Fig. 4 shows the position of the chain at different times and the trajectory of the particle with the number $i = N$. It is visible, how the chain covers the cylinder, then slides off it on the table surface.

5. The problem of disk rotating on the horizontal surface. The disk (hoop) placed with an edge on the table surface and twist round the vertical axis passing through the center of mass. Viscous frictional forces act from the surface and from the outside air. It is necessary to calculate the three-dimensional motion of the disk, to obtain a computer animation.

The disc is modeled by 48 particles located along the rim and connected by rigid rods with a 49th particle located in the center. The particles on the rim are also interconnected: each of them is linked by rigid rods with six particles on one side and six particles on the other side. All particles of the system are affected by gravity force. If any of the particles falls below the given level y_0 (that is, the table surface), its vertical coordinate y_i becomes equal y_0, and the corresponding velocity component υ_{iy} decreases by 1.2–1.4 times and turns upwards. The results of the simulation are presented in Fig. 4.1. That part of the rotating disk, which is closer to us, is drawn by radial segments. Due to friction, the rotation slows down, the angle between the disk plane and the surface of the table is reduced to zero.

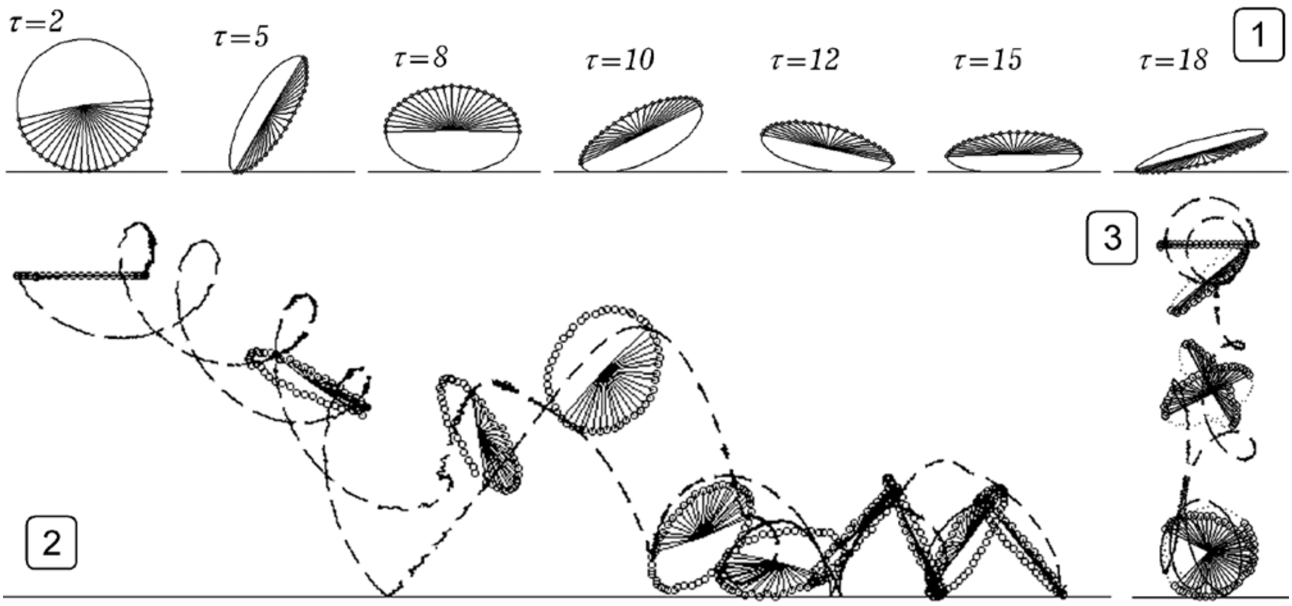

Fig. 4. The motion of rotating disk and its interaction with the surface.

6. The problem of a tumbling disk. The partially elastic disk (or ring) is twisted and thrown onto the table surface. It is necessary to simulate the three-dimensional motion of the disk, get a computer animation, calculate trajectories of some points.

Mentally replace the disk with a system of 48 (or 24) points located on the circumference and interconnected by visco-elastic links. The simulation results are presented in Fig. 4.2. After hitting the surface, the disk recoils, turns over, falls back to the surface, etc. Fig. 4.3 shows the disk movement, in which the center of mass falls vertically downwards and the disk collides with the horizontal surface.

7. The problem of precessing gyroscope. Symmetrical gyroscope rotates around the fixed point in the uniform gravity field. It is necessary to obtain a computer animation, to get dependency graphs of the precession and nutation angles on time for different system parameters.

Replace the gyroscope with a system of fourteen particles, twelve of which are located along the circumference of the radius R, the thirteenth is in the circle center and the fourteenth (stationary) – on the rotation axis (Fig. 5.1). All particles are connected with each other by weightless visco-elastic rods, forming a symmetrical pyramid, at the base of which is a regular dodecagon. Each particle is affected by gravity force $m_i\vec{g}$. The angle between the axis of self-rotation of the gyro AA' and the vertical axis OY is called the nutation angle θ, and the angle between the axis OZ and the projection of the axis AA' gyro on the plane XOY – the precession angle φ. The computer model allows to obtain three-dimensional animation of precessing gyroscope (Fig. 5.2), to calculate the trajectory of the disk center A' in the projection on the XOY plane (Fig. 5.3), to plot the change in the nutation angle over time (Fig. 5.4). In the absence of the medium resistance, the nutation angle makes undamped oscillations, periodically taking values $\theta_0 = \pi / 2$ (curve 1). With the growth of the resistance coefficient r, the oscillation of the nutation angle θ decay faster, the angle θ increases more rapidly to π radians (curves 2 and 3 at $r = 0.05$ and 0.1). If the speed of its own rotation is small, the amplitude of the oscillation $\theta(t)$ is greater (curve 4).

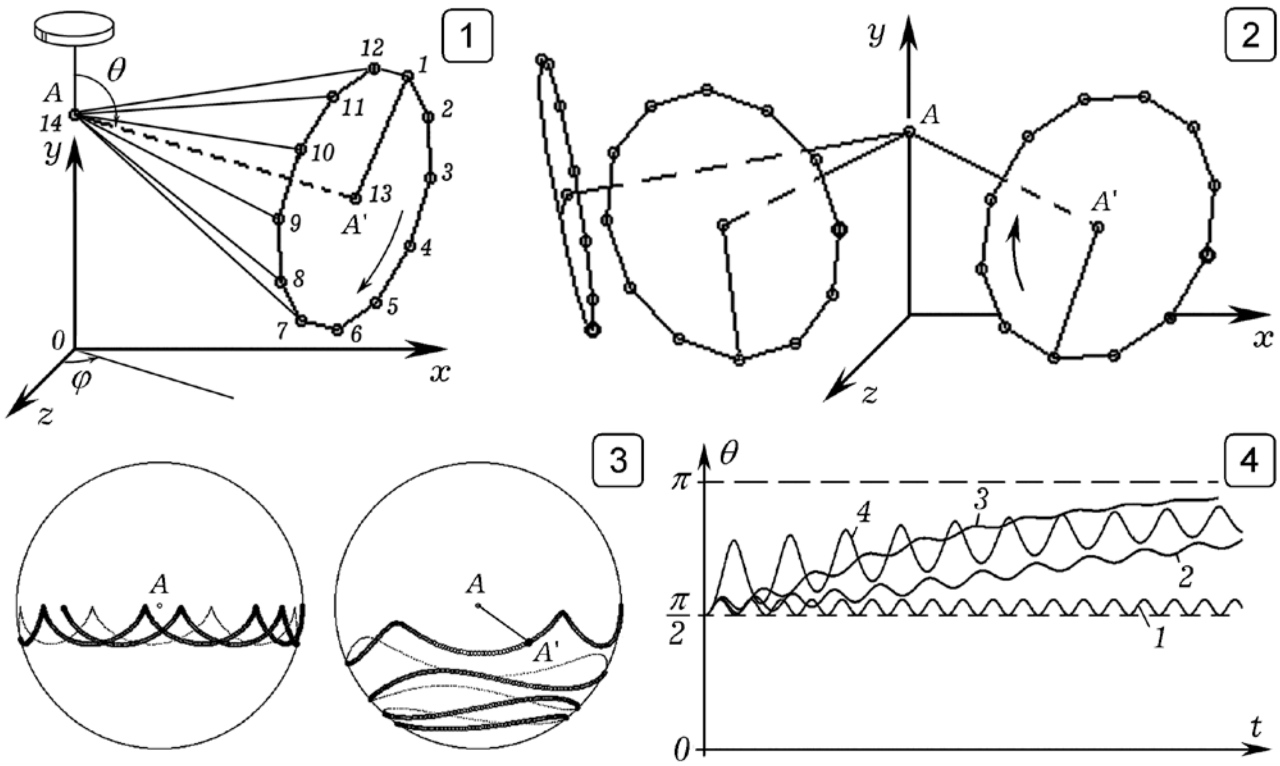

Fig. 5. Modeling of the gyroscope precession in the gravity field.

The analysis of this tasks allows to reveal the following didactic possibilities of two-dimensional and three-dimensional modeling of the viscous-elastic body by the linked particles method: 1) the possibility to study several mechanical phenomena associated with translational, rotational motion, bodies deformation, gyroscope precession etc., to update the knowledge of the relevant mechanics concepts and laws; 2) the possibility to intensify the student's educational and cognitive activity, to increase their motivation to learn and training effectiveness; 3) the possibility to master the computer modeling method, to get acquainted with the solution of various tasks of professional orientation, to explain the algorithms used and the results of modeling on the school or teacher training level; 4) the possibility to develop physical and algorithmic thinking, the ability to use the coordinate method, to carry out mathematical processing of information; 5) the possibility to implement an interactive dialogue between the student and the computer program, during which students set the parameters of the simulated system, the initial conditions and the external influences; 6) the possibility to visualize information about the state of the object, to build dependency graphs of the points coordinates, speed and acceleration on time, the trajectory of the

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points movement; 7) the possibility to create various animations of body movement and deformation, caused by the interaction with other bodies; 8) the possibility to create problem situations that require editing computer programs, changing the system parameters, initial conditions and external influences; 9) the possibility of deepening interdisciplinary connections between mathematics, physics and computer science.

Summary

The discussed models of body movement have great didactic possibilities. Two-dimensional and three-dimensional modeling of solid and visco-elastic bodies by replacing them with a set of particles connected by visco-elastic rods helps to study the large set of mechanical phenomena. The simulation results promote the actualization of knowledge about: 1) the basic concepts of kinematics for the translational, rotational, plane and spherical movements of the body, the laws of dynamics, the conservation of momentum and angular momentum; 2) the methods for the numerical solution of differential equations; 3) programming in Pascal, building graphs and creating the simplest animations that form the visual image of body movement. Such models allow to organize an interactive dialogue between student and computer, to visualize information about the state of an object, to develop physical and algorithmic thinking, to use the coordinate method, to perform mathematical processing of information, to create problem situations, to deepen interdisciplinary connection between mathematics, physics and computer science.

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